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The conference "Urban Effects on Water Quality and Quantity" was held in Urbana, Illinois, on October 20 and 21, 1983. The purpose of the conference was twofold: 1) to summarize the findings of several USEPA sponsored nationwide urban runoff projects; and 2) to provide a forum for the discussion of ongoing and recently completed projects pertaining to urban stormwater runoff quality, urban stormwater runoff quantity and combined sewer overflow issues.

These proceedings are a compilation of papers presented by conference speakers and the transcripts of the two panel discussions held during the conference. The primary technical areas contained in the proceedings are: 1) nationwide urban runoff program-regional summaries; 2) modeling and quantity issues; 3) technical and legal aspects of combined sewer overflows and their regulation; and 4) urban effects on stream and lake sediments.

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Conference Proceedings of October 20 and 21, 1983

at

Jumer's Castle Lodge

Urbana, Illinois

Conference Sponsored by:

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Illinois State Water Survey

Northeastern Illinois Planning Commission

Water Resources Center,
University of Illinois, Urbana-Champaign

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PLENARY SESSION

REACHING A CONCENSUS ON URBAN EFFECTS

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In its least pretentious form a keynote address can be thought of as the means by which a conference officially clears its throat in advance of the more important statements which will follow. It permits the meeting to get started with the appearance and sound of activity which will bring the late arrivals in from the hallways, and is a polite way of bringing to a close those more interesting private conversations.

A more ambitious definition of a keynote address is to consider it an interlocutory device to bring more than a hundred individuals, each from his separate world, into a common focus, in this case, the subject of Urban Effects on Water Quality and Quantity.

The bridging material for achieving this common focus can be a summary of previous events which brought us to this time and place where we can subsequently exchange and assess new knowledge.

The highest level of keynote address is one which challenges the participants to reach some new height of understanding or agreement which will make the meeting memorable - even historic.

I would hope that we might do all of these things.

We should begin by noting that cities are an unnatural anomoly on the landscape, and I'm not sure that nature ever intended for us to so cohabit and change the natural patterns as a consequence.

I recall a strange map prepared many years ago by the U.S. Weather Bureau. It was a kind of annual isohyetal precipitation map of the United States, and showed the areas of greatest precipitation deficiencies. Manhattan Island in New York was the area of greatest deficiency, and the Chicago area was the second greatest area of deficit. The reason for this strange representation is because the map represented precipitation divided by population. On that basis New York is the most severe deficit area.

More in our context we could look at the obverse of the precipitation map and say that cities impact the quality and quantity of water resources far out of proportion to their areas because of the population, their attendant economic activities, facilities and structures. Cities are a major perturbation on the hydrologic landscape.

We determine the urban, or any other effects, on water quality and quantity by the correlation of precipitation and runoff in association with some collection of physiographic and cultural parameters. The setting for performing this correlation is a well-instrumented small watershed for which the input precipitation and the output runoff are associated with all the relevant parameters which modify the correlation.

Ideally the watershed is under control, so that various uses can be applied sequentially, and their effects observed for a sufficiently long period to have statistical validity. Or alternatively, one can manage a pair of watersheds on which practices are introduced on one so that the effect can be compared with the control watershed. In either experimental configuration it is usually required to have some 10 years or more of observations to develop the full range of events and convincing statistical validity.

Experiments of the kind just described were begun in this country some 50 years ago. Many of these were conducted by the U.S. Forest Service on forest and range lands. The hydrologic characteristics of representative watersheds were determined, as were the effects of various silvicultural practices. During this same general time the Soil Conservation Service followed by the Agricultural Research Service operated a nation-wide network of agricultural watersheds, primarily to determine the effect of conservation measures. On both the forested and agricultural watersheds, the goals were modest: to characterize peak rate and volume of runoff, and perhaps, sediment load. Typically, no ground water, no water chemistry, and no aquatic biological measurements were made.

Looking back at that earlier world from the context of urban hydrology and the persepctive of 1983, we can make a couple of observations One is that it was a much simpler time, and secondly that the interest and continuity of support by those federal agencies is what made it happen.

We have enjoyed few of these advantages in the field of urban hydrology. Our watersheds are not controlled, and change is largely regulated by other forces. Most of all, until recently, we have not had the support of a national agency to design, coordinate, and support a program of measurement and analysis. Whether recent federal support will have spanned a sufficient length of time is yet to be determined. In the absence of control watersheds we are forced into modelling and simulation by which we cut and try in an attempt to account for cause and effect.

I would now like to move our thinking closer to real time, and to our reason for being here today. In doing this I wish to acknowledge the help received from two recent papers by Dr. Jacques W. Delleur of the Department of Civil Engineering at Purdue. One of these papers was entitled "Urban Hydrology" which appeared in the U.S. National Report of the International Union of Geodesy and Geophysics for 1979-1982. The other was a coauthored report, "Modeling the Runoff Process in Urban Areas," which appeared in CRC Critical Reviews in Environmental Control, dated July 1980.

We are here at this meeting, either directly or indirectly, because of the comprehensive urban storm-drainage planning required in Section 208 of the Federal Water Pollution Control Act of 1972 (PL 92-500), and also the Clean Water Act of 1977 (PL 95-217), under which the U.S. Environmental Protection Agency has been conducting a 5-year program to assess the nature of the urban runoff problems and the means for controlling them. The EPA responded with the Nationwide Urban Runoff

Program (NURP) of 28 projects of which 14 emphasize water quality impacts on rivers or streams, four in bays and estuaries, eight on lakes, and two on groundwater. One of these was conducted here locally by the Illinois State Water Survey, and was concerned with the effectiveness of municipal street sweeping in the control of urban storm runoff pollution. An extension of that project was an assessment of the impact of urban storm runoff on an agricultural receiving stream. At this conference we will hear reports on the national program as well as the local project and others in the Chicago region and in Wisconsin.

Beyond these we will hear a sampling of reports on the wide-ranging research activities which have resulted, at least in part, from the federal legislation. It has been an exciting time of initiatives and innovation in model building and simulation. It has been a time which has taxed our abilities to invent new acronyms and to maximize the effectiveness of data limited in time and location.

We appreciate the leadership which has been exercised by the USEPA in advancing this field, and becoming the national sponsor and coordinator which had been absent for so long. Appreciation is also accorded the U.S. Geological Survey which has applied an increasing share of its talent and skills to the problems of urban runoff.

Mention also must be made of late Murray B. McPherson and his many associates in the Urban Water Resources Research Program of the American Society of Civil Engineers, who for many years have exercised the principal national leadership in urban hydrology.

It seems to me that the time is now at hand to assess what we have learned to do, and to begin the process of concensus, leading to accepted methodologies with which the urban planners and engineers can do their work. This is the challenge of this conference - to be the turning point by a process of shared experience and judgment by which we can begin to consolidate the far-ranging approaches into a few methods which represent the state of the art.

What we are asking is perhaps the most complex challenge ever undertaken by hydrologists. We are not talking about the undisturbed watershed of a protected natural area where the rhythms of nature prevail, and we simply characterize. We are not talking about the forested area where controlled variables such as tree species and silvicultural practices represent controllable options. What we are talking about is a highly disturbed area with unnatural boundaries. The partially-paved surface changes the balance of surface and ground water. The conveyance channels run the gamut from closed conduits of all descriptions to modified Boneyard Creeks. The water quality is impacted by a variety of point and non-point sources which may require 25 or more parameters to reasonably describe the physical, chemical, and biological characteristics of separate or combined systems.

The goal is to attain a healthy, although highly modified, urban water environment. The immediate challenge is to sort out, assess, and evaluate the meaning of all these introduced complexities as well as control strategies during a 2-day meeting. This is a challenge, indeed. I'm glad that the organizers of this meeting have assembled such a smart bunch of people. Knowing that the nation will spend billions of dollars building and replacing this part of our infrastructure assures that the stakes are high.

PRELIMINARY RESULTS OF THE NATIONWIDE URBAN RUNOFF PROGRAM (NURP)

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INTRODUCTION

The historical concern associated with urban runoff has been with adequate drainage i.e., prevention of localized flooding. Urban development reduces pervious land area and increases the impervious area, such as roof tops, streets and sidewalks, where water cannot infiltrate. Consequently, an urban area will have more runoff that will occur more rapidly for a given storm event, as compared to an undeveloped area. The resulting increases in the rate and volume of runoff have a marked effect on erosion rates and flooding. Thus, it is not surprising that at the local level the principal concern with urban runoff has been quantity.

It is only recently that concern with urban runoff as a contributor to receiving water quality problems has been expressed. As a result of planning efforts initiated under Section 208 of the Federal Water Pollution Control Act Amendments of 1972, the uncertainties associated with the local nature and extent water quality problems caused by urban runoff and the effectiveness of control measures became apparent. The unknowns were so great that when Congress passed the Clean Water Act of 1977 (P.L. 95-217), it deleted Federal funding for the treatment of separate stormwater discharges. There was simply not enough known about urban runoff loads, impacts and controls.

In 1978, after reviewing the past work on urban runoff conducted as part of 208 planning activities, EPA determined that additional, consistent data were needed. Thus, EPA initiated its Nationwide Urban Runoff Program (NURP) to build upon prior work and to provide additional practical information and insights to guide future policy and program development and implementation. NURP includes 28 projects which focused on urban stormwater and water quality. While all these projects are separate and distinct, most share certain commonalities. All are involved with one or more of the following elements: characterizing pollutant types, loads, and effects on receiving water quality; determining the need for control; and evaluating various alternatives for controlling urban runoff.

EPA provided guidance to the NURP projects to allow comparison of results fom all the projects. Data from the NURP projects are currently being analyzed by EPA and the final report on the NURP program will be completed this fall. It is hoped that NURP will serve as a basis to make the best possible policy decisions regarding Federal, State, and local involvement in controlling urban stormwater runoff.

The follwing is a summary of the approach used by the NURP and the preliminary results.

PROGRAM DESIGN

EPA served as the primary coordinator of NURP and provided a communication link to and among the NURP projets. Early on EPA established guidelines for collecting and analyzing data so that the project results would be comparable. These were all based on standard methods and accepted procedures. This was done to insure that any differences found from site to site would be due to factors other than how the data were collected. EPA required quality assurance and quality control of samples and analysis at all phases, including storing the data base.

The emphasis of NURP has been on developing a comprehensive data base for analyzing the characteristics and impacts of urban stormwater on receiving waters. To date, about three million data points have been collected and stored in STORET (a computerized data base system maintained by EPA for the STOrage and RETrieval of water quality data). Currently, about 40,000 data points have been used to provide a preliminary assessment of urban stormwater runoff. Data include: runoff concentrations, flow, atmospheric fallout, precipitation, toxic pollutants and conventional pollutants.

A substantial component of the individual NURP projects was to acquire data from a number of storm events in urban catchments, consisting of precipitation and the resulting quantity and quality of runoff. The principal EPA ojbective has been to develop a concise summary of the characteristics of urban runoff and to examine any similarities or differences in a way which would make possible reliable quantitative statements concerning "transferability" of such data. "Transferability" is a term used to represent the ability to make estimates of uran runoff pollutant loads at locations where it's unfeasible to monitor, by utilizing the national data base and pertinent local precipitation and land use characteristics. This is a particularly important objective, because of the intermittent and highly variable nature of the rainfall-runoff process and the relatively high cost of monitoring programs.

APPROACH

From prior studies and the NURP projects, urban runoff flows and concentrations are known to be highly variable. Substantial variations occur within a particular event and from one event to the next at a particular site. Thus, for this reason a large number of sites and storm events were monitored and a statistical approach was used to analyze the data. Standard statistical procedures allowed probability distributions or frequency of occurrence to be examined and tested. Since the underlying distribution was demonstrated (base e) transforms of all urban runoff load data were used in developing the statistical characterization.

The event mean concentration (EMC), defined as the total constituent mass discharge divided by the total runoff volume, was chosen as the primary statistic. Event mean concentrations were based on flow weighted composite samples for each event at each site in the accessible data base. For the purpose of determining event mean concentrations, rainfall events were defined to be separate precipitation events when there was an intervening time period of at least six hours without rain.

The data were not evaluated deterministically but rather by using statistical techniques. Establishing the fundamental distribution as log-normal and the availability of a sufficiently large population of EMC's to provide reliabiity to the statistics derived, has provided a number of benefits including:

- Concise summaries of highly variable data can be developed.
- Results from different sites, events, etc. can be easily compared.
- Statements can be made concerning frequency of occurrence. One can express how often values will be expected to exceed various magnitudes of interest.
- A more useful method of reporting data than the use of ranges is provided; one which is less subject to misinterpretation.
- A framework is provided for examining "transferability" of data in a quantitative manner.

WHAT HAVE WE LEARNED FORM NURP

We have learned some good news and some bad news about urban stormwater runoff as a result of NURP. First the bad news: urban runoff causes some quality problems in urban receiving waters. The good new is that urban runoff is not as much of a problem as we had suspected in the past.

Part of the explanation for the past overestimation of urban runoff problems relates to pollutant loads. For years we have compared loads from different pollution sources such as treatment plants, industrial discharges, combined sewers and separate storm sewer discharges. On a national basis these figures are large and imposing. They give an estimate of what may be entering our surface waters. Good estimates, but nonetheless, estimates. Estimates are no better than the assumptions upon which they are based.

The first assumption typically used in estimating loads is that unit loads apply everywhere. A second assumption, is if you reduce the load, you reduce the problem. These are not bad assumptions for making a first cut at estimating pollutant loads associated with urban stormwater runoff. Over the past 10 years we have made several cuts and we are begining to understand, based on observation and measurements just how good these estimates and their underlying assumptions are.

The first assumption that unit loads apply everywhere loses meaning upon closer scrutiny. One unit load is not representative of actual loads from all urban areas; there are significant differences. For nonpoint sources the differences are greater than for point sources. While POTW's and industrial discharges vary little from city to city and state to state, hydrology varies substantially. While people directly generate point source pollution and sewers convey it to receiving waters, rainfall and the corresponding runoff generates nonpoint source pollution. If there were no rain, there would be no discharge of nonpoint source pollutants. The hydrologic cycle is the driving force; as it rains pollutants from nonpoint sources are washed to receiving waters. Therefore, we need to look closer at this cycle to understand nonpoint source pollutant loads.

First, we see that rainfall is not distributed uniformly over the United States. Second, it does not rain the same amount of time nor even during similar times. Some areas of the country exhibit summer thunderstorms, others have no rain between April and October. In some areas it rains 150 days a year and in others 35 days a year. If as was pointed out earlier, nonpoint source discharges are dependent on rainfall and corresponding runoff, then there will be wide variations in pollutant loads from different parts of the country i.e., one unit load is not representative of actual loads everywhere.

The second past assumption regarding urban stormwater is that if you reduce pollutant loads in runoff you reduce the "problem." One of the early NURP tasks was to establish a basis for deciding if urban stormwater was creating a "problem" in selected receiving waters. It is not adequate to merely say, yes we have a problem or no we do not. There must be some rational basis for making the distinction. For example, to say that loads are high and therefore a problem exists is not sufficient to justify that a problem indeed exists.

To better assess problems asociated with urban runoff, NURP developed a three-level definition. Urban runoff was defined as a problem if: 1) a beneficial use (i.e., swimming, fishing, drinking water) was denied; 2) if a water quality criterion was violated; and 3) if you think it's a problem. The "you" in this case is a local government or community, anyone but the Federal government. Thus, our experiences with NURP have shown that the second assumption, if you reduce pollutant loads you reduce the "problem", is overly simplistic.

PROBLEMS FROM URBAN RUNOFF

Once we developed our three-level problem definition we felt it would be a simple matter to count the problems by type and put them in a nice little table. But it did not work out that way.

The uses of the waters at each of the project sites were many. Some of the waters were used for contact recreational sports, for fishing, or for drinking water, others had more limited uses. But when it came right down to it, we could find only one project that had a beneficial use denied unequivocally by urban runoff. This was shellfish bed closures caused by excessive fecal coliform counts in the runoff from Long Island, New York. Several other NURP projects did discover potential short-term impacts on beneficial uses. For example, Mrytle Beach documented fecal coliform counts exceeding EPA criteria immediately after storm events. The beaches have not been closed, but the counts warrant keeping a close eye on bather's health. Additionally, in Mystic Lake in Massachusetts, on occasion local officials have closed bathing beaches due to high fecal coliform counts. However, in this instance high fecal coliform counts were due to both combined sewer overflows and stormwater runoff. Besides the above examples, no other level one problems were found by NURP.

Most of the problems identified by the NURP projects fell into the level two classification. Violations occur frequently for most criteria. The more serious violators are the heavy metals: lead, copper and zinc. Copper is easily the most toxic of the three, yet from limited biological studies associated with the NURP program, no ill effects have been documented. One possible reason for this is the limited duration of the vast majority of the storm events.

From the type of statistical analyses that were done with the NURP data it is possible to ask and answer questions like, how much and how frequently do concentrations of certain pollutants exceed EPA criteria. NURP has done a limited amount of this type of analysis and the results have been enlightening. For example, the Rapid City, South Dakota NURP project suspected that the lead in urban runoff to Rapid Creek caused the loss of the rainbow trout population. Based on the statistical analyses developed by NURP and given our use of modified criterion based on duration of events, the following results were obtained:

1. During all storm events the concentrations of lead in the stream violate drinking water criterion. The drinking water criterion is quite low; 50 ug/l.

2. Lead concentrations in the stream would be expected to be high enough to kill 50 percent of the rainbow trout in the stream about once in 10 years.

This example illustrates an important point regarding frequency of criteria violation. The lethal concentration over a 96 hour period within which 50 percent mortality will occur is well known and used by us and others, however, storm events do not last for 96 hours. In Rapid City, for example, their median duration is about eight hours. Thus, what is the LC_{50} for eight hours? Using an established technique, published in the Federal Register, we were able to detemine what the concentraion is, and it is considerably higher than the 96 hour LC_{50} value i.e., about 20,000 ug/l lead. And the frequency of this very high concentration is quite infrequent i.e., about once in 10 years. Thus, based on analysis of the NURP data it is unlikely that lead from urban stormwater is significant cause of the loss of the rainbow trout population.

To date, we have only looked at data from Rapid City but we plan to continue working along these lines to analyze data from other communites. Further analysis of the NURP data will help us answer the question of whether "urban runoff is a problem everywhere" and what type of problems exist.

As we noted earlier, urban communities' primary concern regarding urban stormwater runoff is drainage. The primary perceived impact from increased stormwater is localized flooding problems. However, a number of the NURP projects concluded that urban runoff can also be a significant cause of habitat disruption. For example, fish spawning areas can be destroyed by increases in the rate and volume of runoff. NURP recommends further study of this issue.

In addition to the above findings, following are some more conclusions from NURP on the nature and extent of problems from urban runoff:

- Conventional pollutants, e.g., total suspended solids, biochemical oxygen demand, chemical oxygen demand, total phopshorus, total nitrogen, do not cause significant water quality problems in most cases.

- With the exception of some heavy metals and organics, most of the 129 pollutants on EPA's priority pollutant list were not found in urban runoff. Of the heavy metals found (e.g. lead, zinc, and copper), copper is the pollutant of most concern because of its high solubility and frequency of occurrence in urban runoff samples. Lead is prevalent, but not in a toxic form, and it is becoming less prevalent each year.

- Organic priority pollutants were present in certain urban runoff discharges. Where present, and the beneficial use is a potable water supply there is a potential for concern, although there may be mitigating factors which will cause this not to be a "problem".

- Fresh water aquatic life is potentially threatened by the concentrations of nutrients and toxic pollutants in urban runoff. This conclusion is based on the fact that a number of heavy metals are consistently found in urban runoff in high concentrations relative to suggested toxic limits for aquatic life.

- Coliform bacteria are present in high levels in urban runoff and violate water quality criteria most of the time. As a result, beaches may be closed as well as shellfish beds.

URBAN RUNOFF CONTROL MEASURES

The NURP projects evaluated a limited number of conventional control measures for controlling the quality of urban stormwater. Practices evaluated include street sweeping and detention basins. The following is a summary of NURP's findings regarding these practices:

Street sweeping for aesthetic purposes is appropriate but the benefits of this practice for water quality were not verified by the NURP projects. The NURP projects reported varying levels of effectiveness and preliminary results indicate that street sweeping for water quality purposes has very limited effectiveness in most of the United States. One exception to this is in areas with distinct wet and dry seasons. It may be effective to sweep before snow melt events, but even in those instances the effectiveness should be closely evaluated on a case-by-case basis. On the basis of the NURP studies, it would appear that urban housekeeping practices such as pet waste control ordinances, public education programs focusing on litter control and proper fertilizer application, construction of detention basins, and other source controls may be more effective than street sweeping in established urban areas.

The NURP projects report that wet basins are very effective for removing many of the pollutants in urban stormwater, if they are designed properly. This conclusion is based on actual monitoring of the performance of eleven detention basins by NURP over several years. For example, reductions of up to 80-90 percent were obtained for most conventional pollutants in these detention basins. NURP has developed a method for sizing basins on the basis of the NURP data base and this should provide valuable information for designing basins for water quality purposes.

The NURP results indicate that the quality of urban runoff can be controlled more easily and at less cost in developing and redeveloping areas. Developments can be designed to increase infiltration by the use of natural drainageways, greenways, infiltration trenches, and detention basins. The potential for controlling the quality of urban runoff in stable, established urban areas is limited by the high cost of many runoff control measures such as surface tunnels, stormwater diversions and detention basins. Also, NURP results indicate that lower cost housekeeping practices such as street sweeping have limited effectiveness. Other types of source controls (litter ordinances, pet waste controls, detention basins, catch basin cleaning, etc.) appear to be more effective than street sweeping.

CONCLUSIONS FROM NURP

Although some of the NURP results are directly transferable, the most far-reaching conclusion to emerge from NURP is that both water quality problems arising from urban stormwater runoff and control measures to prevent and alleviate such problems are heavily site-specific in nature and therefore must be approached from that perspective. Many factors affect the nature and severity of water quality impacts generated entirely or in part by urban runoff and the effectiveness of management practices utilized to alleviate or avoid those impacts. Rainfall, hydrology, soil and receiving water characteristics, land use, construction activities, extent of impervious surfaces and climate are some of the factors which individually and in varying combinations modify the impacts of urban runoff and the effectivenss of controls. The number of these factors and their interactions prevent broad, general conclusions applicable to all, or even most, situations and prescription of catergorical remedies.

The NURP studies indicate instead that suspected urban runoff induced water quality problems must be carefully assessed site-by-site, that the validity and applicability of any generalizations must be constantly tested, and the performance of control measures must be monitored on a continuing basis. Within these contraints, however, certain general conclusions summarized above regarding the nature and scope of urban runoff problems nationwide and the effectiveness of selected control measures is possible on the basis of the NURP studies.

FUTURE DIRECTIONS

EPA administrator Ruckelshaus discussed five issues in his testimony on June 14, 1983 to the Senate Public Works Committee regarding the Clean Water Act reauthorization. Nonpoint source pollution was one of the five issues. In his testimony he stated that nonpoint source pollution was a serious problem. Additionally, a number of Congressional representatives are concerned about this source of water pollution and a number of different types of programs have been proposed to deal with nonpoint source pollution ranging from technical assistance and cost sharing to regulation. Just exactly what is going to happen at the Federal level regarding nonpoint source control is unclear.

But it is clear that NURP projects provide a comprehensive data base upon which some decisions can be made regarding controlling urban stormwater runoff. It is hoped that the NURP data can be used by local decision-makers to provide a basis for decisions regarding te management of urban stormwater runoff. NURP has not provided all the answers but some of the questions regarding the nature and characteristics of urban stormwater runoff and the effectiveness of control measures have been answered.

Experiences with the NURP projects indicate that a number of states and local communities have already begun to develop and implement stormwater management programs incorporating water quality objectives. However, such management initiatives are at present scattered and localized. The challenge now is to share the experiences gained by these communities and the NURP projects to encourage more widespread adoption of programs to address water quality problems associated with urban stormwater runoff.

URBAN HYDROLOGY STUDIES BY THE U.S. GEOLOGICAL SURVEY

by Ernest D. Cobb
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INTRODUCTION

The U.S. Geological Survey (USGS) has been involved in urban hydrologic studies since at least the 1950's. Many of the early studies concentrated on urban flood problems and the effects of urbanization on flood-peak magnitudes and on flood-hydrograph shapes. In recent years, the emphasis of urban hydrologic studies has shifted towards the effects of urbanization on the quality of runoff from urban areas and of the effects of this runoff on receiving waters.

In the early 1970's, pilot projects were conducted in Miami, Fla.; Denver, Colo.; and Portland, Oreg. The pilot studies provided considerable information regarding methodology and instrumentation needs for collecting urban hydrologic data.

Small urban watersheds respond rapidly to rainfall; peaks occur quickly, and the flow often returns to base-flow or zero-flow conditions within a few hours. Automatic samplers were used to collect a number of samples during these short-duration runoff events. It was observed in the pilot studies that atmospheric fallout could be a major contributor to urban runoff loads for some constituents. Thus, in addition to collecting precipitation, runoff, and runoff quality data, it became apparent that atmospheric fallout quality information should also be collected. The pilot studies also provided some information on the magnitudes of loads which could be expected in the runoff from urban areas.

In 1978, the USGS and the U.S. Environmental Protection Agency (EPA) entered into an interagency agreement for joint urban hydrologic studies. A technical coordination plan was developed as part of the USGS/EPA urban hydrology studies program. This plan is a guide to both EPA and USGS in data-collection efforts.

The objectives which were established in the coordination plan are as follows.

1. To establish a consistent and accessible data base for typical urban watersheds in each study area. Data will consist of rainfall, runoff, water quality, and other environmental factors.
2. To determine the magnitude and frequency of storm-runoff loads of water-quality constituents from typical urban watersheds.
3. To develop methods for estimating storm and annual loads of water-quality constituents for unsampled watersheds in each urban-study area and to identify pollution sources.

4. To test the effectiveness of storm-water management practices such as street sweeping and detention storage.
5. To determine data-base needs and to evaluate methods of transferring information to ungaged watersheds in other regions.

The purpose of this paper is to discuss the current main thrust of the USGS in urban hydrology. This thrust primarily involves objectives 1, 2, and 5.

DATA COLLECTION

Urban hydrology data have been collected at a cost of several million dollars over the past few years. These data will not be available to most potential users unless they are compiled and well documented. Potential users of these data include various Federal, State, and local agencies, as well as universities and consultants.

The data which have been collected include the following:

- Precipitation quantity and rate
- Precipitation and dustfall quality
- Storm-sewer flows and streamflows
- Quality of runoff
- Characteristics of studied basins
- Environmental activities

Precipitation data were usually collected by a tipping bucket rain gage which records each 0.01 inch of precipitation. The number of rain gages operated within a specific study area varied with the size of the study areas, the number of watersheds being studied, and the proximity of the watersheds to other study watersheds. Usually at least one rain gage was operated in each studied watershed.

Many of the study areas included one or more collectors for obtaining rainfall and dustfall samples for quality analysis. During dry periods, a cover was in place over the precipitation collector and the dustfall collector was uncovered. When precipitation occurred, an electronic sensor would cause the cover to move over the dustfall collector and leave the precipitation collector open to collect a sample. Dustfall was generally accumulated for a month and the entire accumulated sample obtained for chemical analysis. Precipitation quality from each storm event was analyzed in some studies. In other studies, precipitation was collected for an entire month prior to a sample being obtained for analysis.

Flows were measured in storm sewers, artifical channels, and in streams and rivers of various sizes. Flumes and weirs were used in some open channels as well as in some closed storm sewers. In a number of studies, electromagnetic flow meters were used to collect flow data--these were especially valuable where backwater existed. When possible, theoretical stage-discharge or stage-velocity discharge ratings were checked by current-meter measurements or, in some cases, by dilution-type measurements.

Storm-runoff samples were usually collected with automatic samplers. Some sites were equipped with programmable controllers so the interval between sample collection could be varied depending on factors such as stage or the rate-of-change of stage. Manually collected samples were also obtained for some runoff events. A few base-flow samples were usually collected at sites where base-flow conditions existed.

Most samples were analyzed for a number of constituents and other properties. These included the following broad categories:

- Sediment
- Specific conductance
- pH
- Dissolved solids
- Nutrients
- Metals
- Major cations and anions
- Carbonaceous substances
- Oxygen demanding substances
- Organics
- Bacteriological indicators
- Temperature

The following characteristics of the catchments were obtained.

- Catchment topography and drainage boundaries
- Drainage basin area
- Land uses
- Impervious areas on smaller basins
- Storm-sewer locations and characteristics on smaller basins

Additional characteristics such as catchment and channel slopes and soil properties were also determined for many catchments. Since all of the above characteristics may vary during urban development, the characteristics were defined for the study period.

Information was also obtained on environmental activities on the catchments during the studies. These included frequency of street sweeping, fertilizer and pesticide applications, refuse collection practices, street deicing activities, traffic conditions, and other activities which may have an impact on constituent loads from the study areas. The collection of this type of data was not as consistent among study areas as for the other types of data.

DATA COMPILATION AND DOCUMENTATION

One of the primary efforts in the USGS urban hydrology program at present (1983) is to compile, check, and store urban-runoff and related data for easy access by potential users. This includes a description of the data placed in storage and the preparation of instructions for accessing the data. A complementary effort is the documentation of the catchment characteristics as they existed at the time of the study. The methods will be discussed in a following section.

In order for data from a site to be included in the compilation, the site must have concurrent rainfall, runoff, and water-quality data for at least five storm events. In addition, selected catchment characteristics must be identified. One hundred and twenty-one sites located in 21 States and 23 urban areas have been identified as meeting the criteria (figure 1).

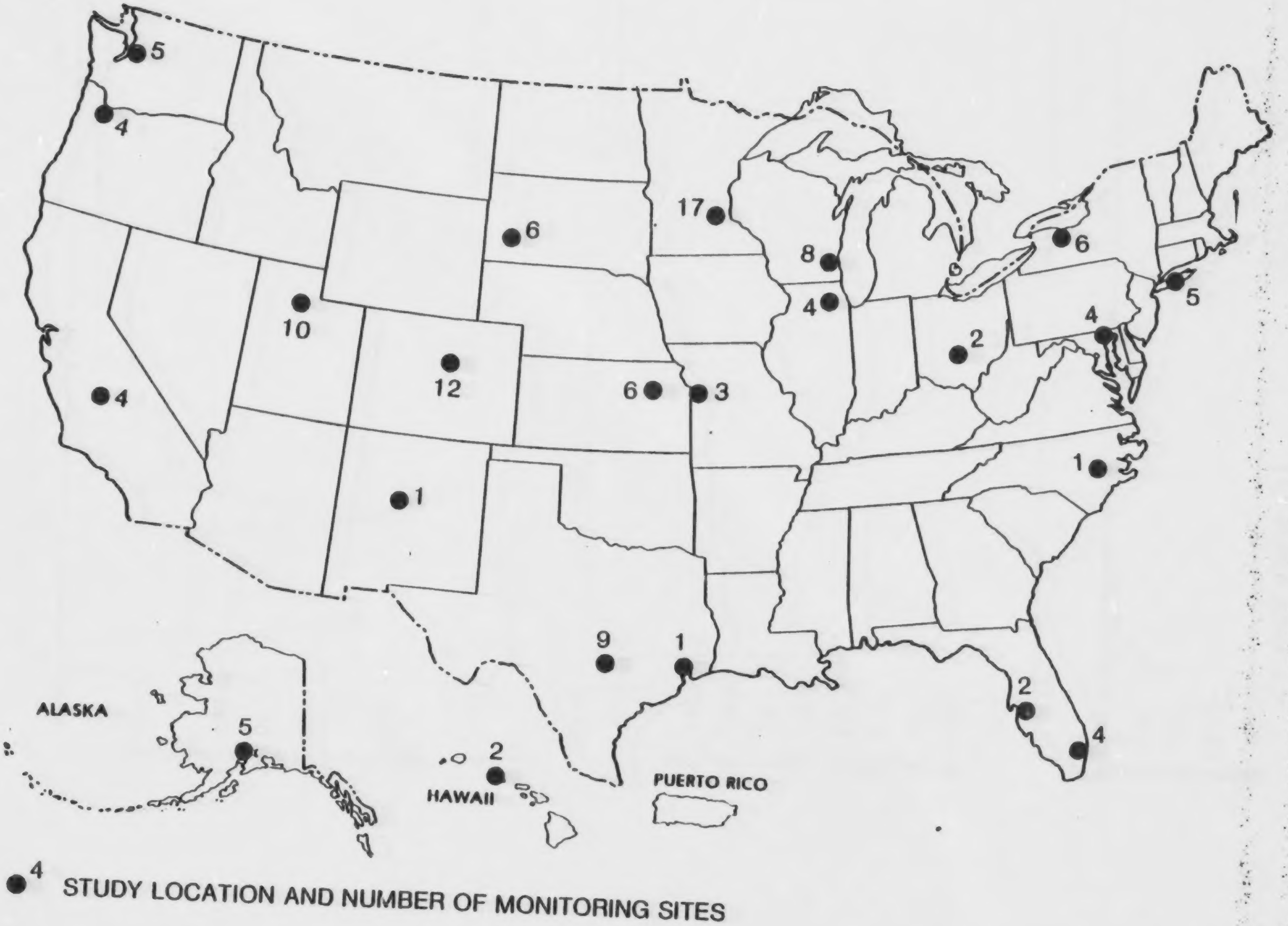
Most of the data (except catchment characteristics) are currently on the USGS WATSTORE data storage system but some still must be entered into the system. The data will be retrieved from WATSTORE and moved into a special data-management system. All time-series data are then plotted and examined for obvious errors (figure 2). After checking the data and correcting obvious errors, the data will be placed on magnetic tape in a common format.

Finally, a report will be prepared describing the types of data on the tapes, the number of storm events for each site, the data format, and some catchment characteristics. The reports and the data tapes will be distributed by the USGS National Water Data Exchange Program (NAWDEX).

WATERSHED CHARACTERISTICS DOCUMENTATION

Watershed characteristics are needed to aid in interpreting urban hydrologic data. Therefore, a report will be prepared which will include maps for all sites with the following features.

1. General study area showing the watersheds studied in that area and the monitoring sites.
2. Specific watersheds which were studied showing:
    a. Watershed boundaries
    b. Topography
    c. Land uses
    d. Impervious areas (small watersheds only; figure 3)
    e. Storm-sewer locations (small watersheds only; figure 4)


5
4
4
10
12
6
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6
3
8
4
9
1
2
6
4
5
1
2
4
ALASKA
5
HAWAII
2
PUERTO RICO
4
STUDY LOCATION AND NUMBER OF MONITORING SITES

Figure 1.—Urban sites with concurrent rainfall, runoff, and water-quality data.

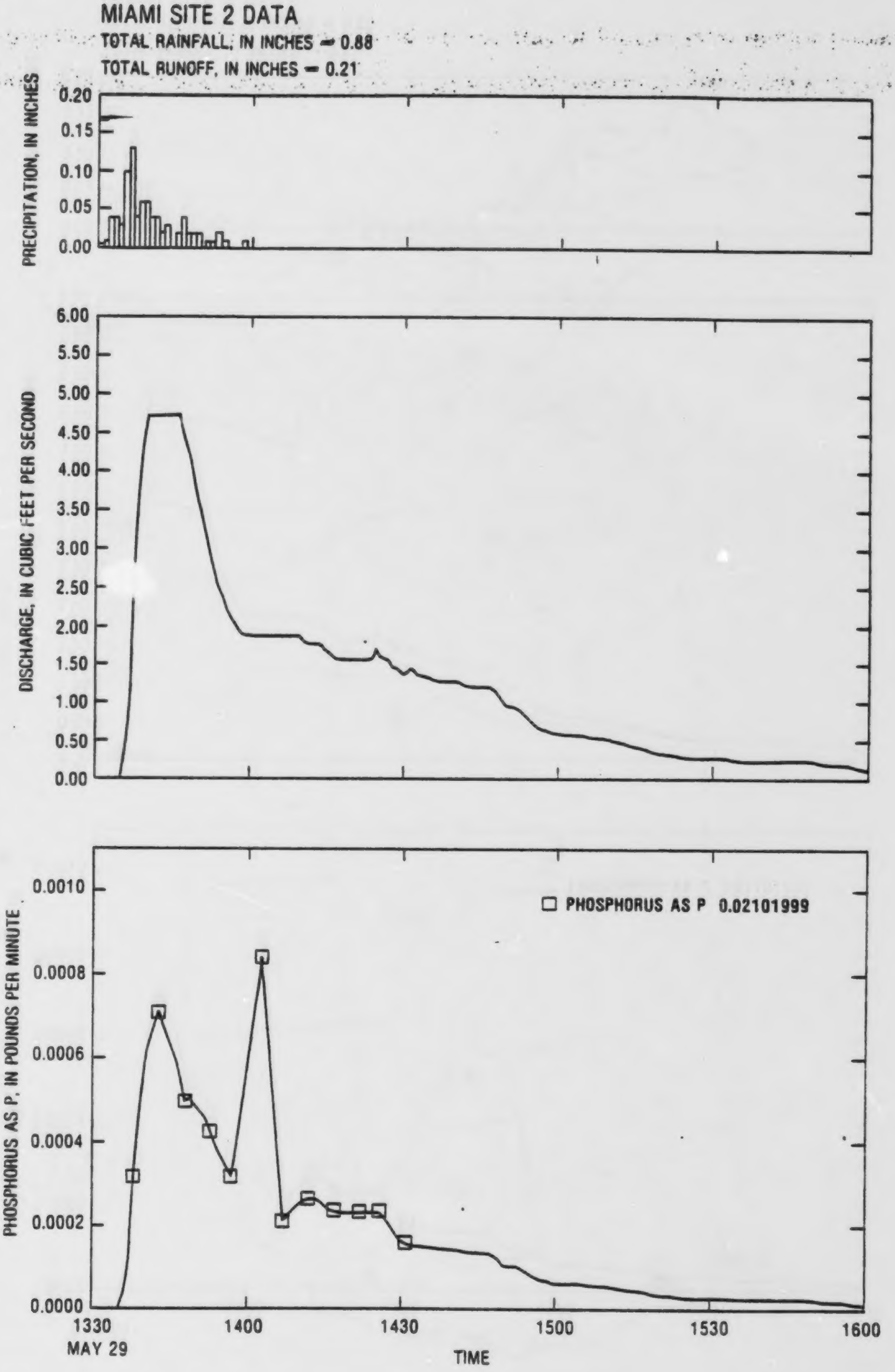
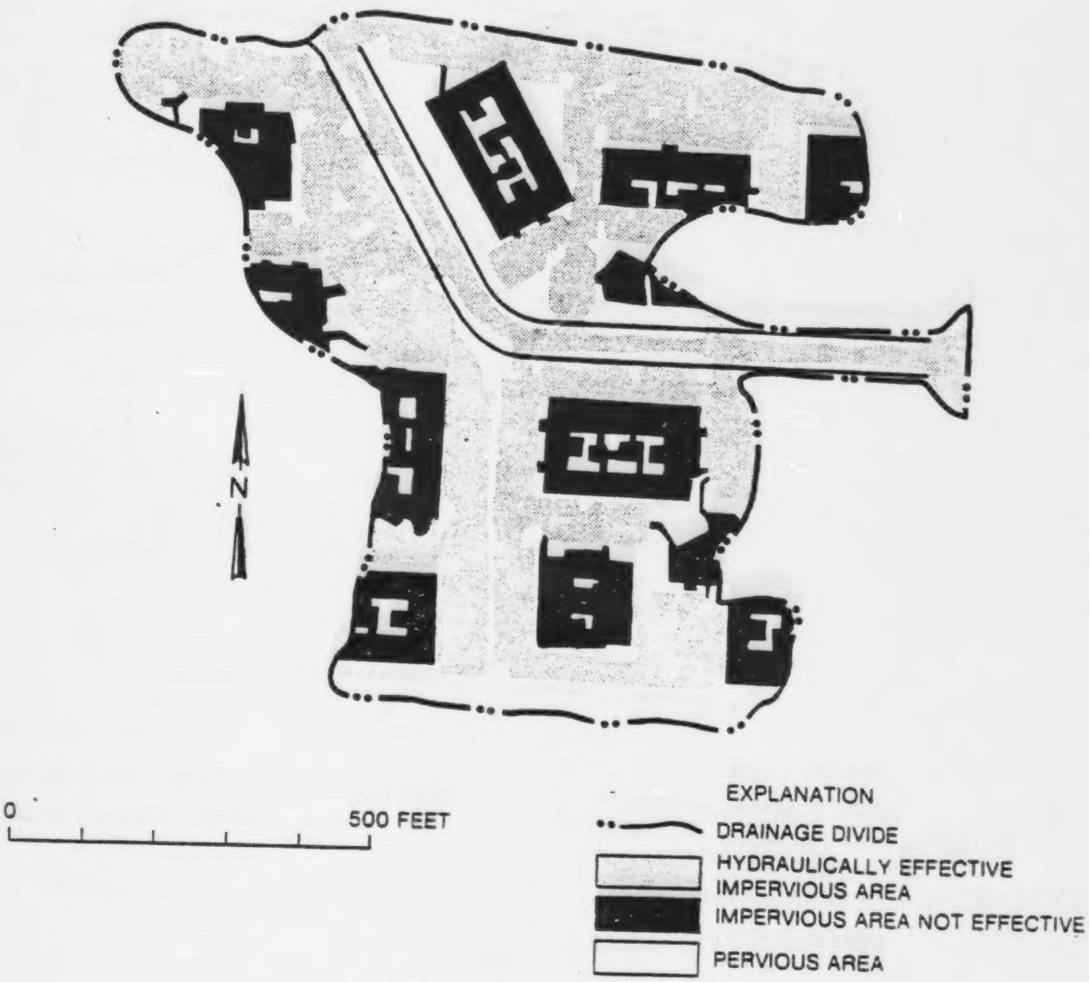


Figure 2.—Example data plots for error checking.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IMPERVIOUS AREA NOT EFFECTIVE
PERVIOUS AREA

Figure 3.—Example map showing impervious areas.

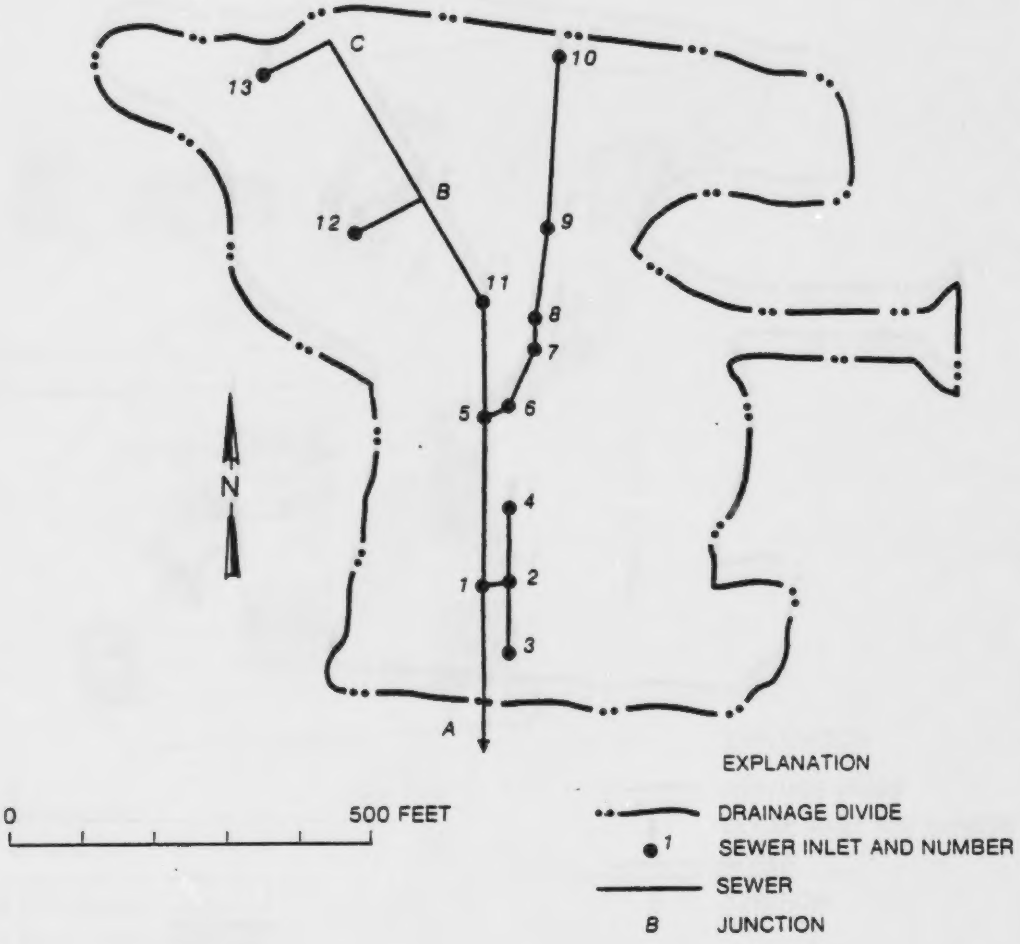
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Figure 4.—Example map showing storm drainage system.

Tables or individual values will be provided for each studied watershed for the following characteristics:

1. Drainage area
2. Percent of impervious area
3. Basin and channel slopes
4. Percentages of various land uses
5. Storm-sewer pipe sizes and slopes (small watersheds only)
6. Climatic information
7. Other information as appropriate and available

FUTURE PLANS

An agenda for future urban study activities in USGS is as follows:

1. Complete the data compilation in 1984.
2. Complete urban watershed characteristics documentation during 1985.
3. Analyze the urban data from a national perspective by the end of 1986.

Plans for the third item on this list are still being made. Several of the objectives of the urban hydrology program were treated in reports of the individual studies. Future data analysis will concentrate on objectives which require a more national perspective including:

1. To determine the magnitude and frequency of storm runoff loads of water-quality constituents from monitored urban watersheds.
2. To develop methods of transferring urban data to ungaged watersheds in other regions.

Local urban runoff studies will undoubtedly continue after the agenda shown is completed. After further evaluation and analysis of the existing data are done, it will be easier to determine future directions for urban hydrology studies.

SUMMARY

The USGS is involved in compiling and documenting urban hydrology data from 121 sites located in 23 urban areas in 21 States. This compilation involves checking the data for errors, placing the data on magnetic tapes, and preparing a report describing the data on the tapes and how to obtain copies of the tapes. This effort is expected to be completed in 1984.

A complementary effort is to document the characteristics of studied urban watersheds. A report will be prepared showing maps and tabular information describing the watershed characteristics. This effort is expected to be completed in 1985.

Analysis of the compiled urban data will concentrate on the determination of magnitude and frequency of selected constituent loads and on developing methods for transferring urban hydrologic information to ungaged watersheds. This effort is expected to be completed in 1986.

URBAN RUNOFF, AN UPDATE ON RESEARCH ACTIVITIES AND POLICY AT THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

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The current Water Quality Management Program at the Illinois EPA is an outgrowth of several phases of planning mandated under the Federal Clean Water Act, as amended. The framework for the program is the Water Quality Management Plan which contains problem assessments of nonpoint sources of pollution and proposed solutions and implementation programs for both point and nonpoint source control. Urban runoff and its impact on receiving streams was one element examined in the planning process. This paper outlines the water quality planning process in Illinois, highlights work completed in the urban runoff area, and gives a scenario of water pollution control programs during the next 5-10 years.

Traditionally pollution control efforts of the IEPA dealt predominately with point source pollution, mainly sewage treatment plants, until the mid seventies. The Agency has had ongoing permit programs in sewer construction, sewage treatment programs and the operation of sewer treatment plants for years. One of the areas overlooked, especially in the midwest, was nonpoint source pollution. In the mid seventies the Agency began to address nonpoint sources of pollution as mandated in the Clean Water Act. Over 20 million dollars were expended on the water quality process in Illinois between Federal Fiscal Years 1976 and 1981. The planning was completed by the IEPA and several areawide planning agencies with the support of contractors, universities and individuals who participated on task forces and work groups. Many of the funds were expended on basic data collection, research, monitoring and program evaluation during three distinct planning phases.

Phase I Basin Planning, promulgated under Section 303(e) of the Clean Water Act, was completed prior to July 1976. Water Quality assessments were completed for 14 river basins in the state. Each basin assessment included: a complete inventory of wastewater discharges originally included in the NPDES program, an assessment of ambient water quality, an analysis of existing water quality problems and a segment by segment assessment of those violations expected to continue in streams if additional control measures were not implemented.

Phase I Basin Planning was followed by Phase II and Phase III Planning authorized under Section 208 of the Clean Water Act. Phase II began in

1975 with the designation by the governor of the Northeastern Illinois Planning Commission (NIPC), the Southwest Illinois Metropolitan and Regional Planning Council (SIMPAC) and the Greater Egypt Regional Planning and Development Agency (GERPD) as the Water Quality Management Agencies in the 19 counties under their jurisdiction. The IEPA conducted WQM planning in the remaining 83 counties of the State.

During Phase II Planning the Agency identified the relationships between water quality conditions and various landuse practices as well as the various technical and institutional control options for eliminating point and nonpoint pollution. Problem assessments were completed in the areas of agriculture (soil erosion, sedimentation, pesticides, and fertilizer management), ground water, mining (oil brine waste control and mineral extraction), urban stormwater, construction erosion, hydrographic modifications, residual waste, and on site disposal. In addition, the agricultural nonpoint source and lake programs were developed. Phase II activities resulted in the development of comprehensive water quality management plans by each of the 4 Water Quality Management planning agencies. Pollution sources were identified for each planning area and locally acceptable point and nonpoint control measures were recommended. In addition, institutional arrangements for plan implementation were developed. At the end of Phase II the Governor certified the plans and designated three area wide agencies and the IEPA as continuing planning agencies as required under the Clean Water Act Amendments of 1977.

Phase III planning encompassed all work completed after May 1979. Phase II studies determined these areas where the data base and/or causative relationships were not complete enough for decision making purposes. Phase III projects concentrated on developing an adequate data base, the transfer of information and control approaches and control strategies for problem resolutions.

Pollution from urban runoff was evaluated in both Phase II and Phase III planning. In 1976 the Agency contracted with varioius private and governmental groups to perform detailed water quality and biological assessments in eight Standard Metropolitan Statistical Areas throughout the nondesignted portion of the state. The studies monitored and evaluated what the pollution problems were in each particular community. Study results indicated that urban runoff did affect the water quality of receiving streams. In particular lead, copper and iron were in excess of general use water quality standards and suspended solids and biological oxygen demand (BOD) often exceeded levels which are applied to point source dischargers. Lead, copper and iron were found to exceed the existing general use water quality standards 25-30 times per year at various points within each study area with the once a year maximum at times reaching levels 15 to 20 times above the standard.

These findings and numerous solutions were presented in the 1979 Water Quality Management Plan. However, it was the consensus of the Agency and the local steering committees that the studies did not define the extent of water quality impact on receiving streams. Additional work characterizing urban runoff, assessing water quality impacts and evaluating the effectiveness of street sweeping and detention storage were recommended.

In 1978 the Agency was chosen, by the USEPA, as one of twenty-eight participants in the Nationwise Urban Runoff Program (NURP). The Agency's project was locted in Champaing Illinois and evaluated the effectiveness of street sweeping as an urban runoff pollution control measure, characterized types and loads of urban pollutants, and assessed the impacts of runoff from Boneyard Creek, an urban stream, on its receiving stream Saline Creek. The project commenced on June 1979 and was completed in March 1983.

During the early phases of the study a complex monitoring program was run and street sweeping was evaluated as a specific pollution control method. This study indicated that although street dirt loads were reduced when streets were swept, there was no reduction of runoff pollution loads attributable to street sweeping.

In the last phases of the study the actual impact of urban runoff on a receiving stream was evaluated. The urban stream system was characterized as was the agricultural drainage flowing into the stream. The impact of the urban stream on the rural stream and the effects of adding a sewage outfall into the rural stream were also evaluated. In essence a point nonpoint trade off scenario was studied.

The major impact of urban runoff on the receiving stream water quality was the elevation of lead, copper, and iron above the general use standards in the receiving stream during 80-90% of all storm events. There did not appear to be an impairment of biological integrity from urban runoff, because the metals are associated with suspended solids and are not available to the biological community. This is evidenced by the lack of significance difference between fish communities above and below the urban sources.

Total suspended solids phosphorus, ammonia nitrate, TKN, nitrate, and chemical oxygen demand were also found to rise 5-10 times above their ambient levels after storm events. However, all elevated levels were of short duration, 2-3 hours, and general use standards do not appear to be an appropriate yardstick to measure the problem. The study indicated that the largest impact of stormwater may be streambank erosion and habitat destruction resulting from the increased quantity of water passing through the stream during storm events. During the majority of flow conditions the impact of the sewage treatment plant far outweighted both the agricultural and urban runoff impacts in this stream.

The Champaign study and most other NURP projects indicate that, although some degree of impairment of beneficial uses may result from urban storm runoff, in most cases, the degree of impairment is not as serious a water quality problem as believed when the NURP program started in 1979.

From a standpoint of pollution control and water use we do have across the board water quality impacts from urban runoff both nationally and within the State of Illinois. Unlike some of the other categorical nonpoint source problems, urban runoff is generally a local area problem and generally the pollution problems that result are very specific to a particular water body. In some cases urban runoff does warrant control measures. However local governments have the primary responsibility for controlling urban runoff.
The Agency's primary role will be to work with the areawide planning commissions and other state agencies to ensure that appropriate municipal and county governments implement measures to work toward reduction of impacts from urban stormwater runoff.

The limited control strategies available to control runoff pollution in developed areas is a major issue. The studies of the best management practices that could be used on urban runoff suggest that detention/retention is the preferred control practice in developing areas. However it is difficult to retrofit basin in completely developed areas. In the future we must determine how we can reduce pollutant loads from developed areas knowing that certain wholesale treatments such as streetsweeping will not be as effective solutions as hoped. In addition, one must answer the most effective manner in which to address future urbanization problems. The Agency supports, and will encourage, municipalities to adopt and enforce adequate stormwater detention ordinances as well as measures to ensure maintenance of detention basins where appropriate. The Agency also supports measures that will address both the quality and quantity aspects of runoff to maximize benefits attained.

The Agency encourages USEPA to develop technical guidelines and specifications for the design of wet bottomed basins which the Agency can use in technical information transfers with local governments. In addition, the possibility of cost-sharing programs for communities to defray installation costs must be investigated and evaluated.

The Agency supports the application of performance zoning concepts that encourage reduction of urban stormwater pollution. In addition, drainage and water quality management should be incorporated into land development plans at an early stage. The Agency also supports other management practices, where appropriate, such as catch basin cleaning, previous pavement surfaces, increased vegetative cover, grass waterways, wetland storage, sedimentation and erosion control and measures to control runoff from open storage areas. All these actions allow an overall pollution control strategy addressing several areas of non-point source pollution and enables the development of a control strategy utilizing the best combination of control measures.

The major focus of current program efforts is the transition from planning to implementation of both point and nonpoint source pollution solutions. As part of the transition the 4 water quality management plans has been consolidated into one document called the Illinois Water Quality Management Plan which proposes water quality management strategies for the entire state.

Over the next five years the Agency will continue to address major statewide problems. From a statewide perspective agriculture and hydromodification are probably the only two nonpoint source problems that impact every region of the state.

However, from the local and regional perspective, numerous other categorical problems such as mining, construction erosion and urban runoff can have severe water quality impacts in these particular areas. There must be a balanced mix of control strategies for all categorical areas. These implementation strategies will be targeted on a local geographical basis and provide for appropriate control of all catagories of NPS. The control plans should consider all sources and a mix of solutions to achieve overall water benefits.

The key short and long term concern will continue to be siting of facilities whether it is for pollution control, housing farmland fertilizer distribution centers or others. Most of man's effects reflect siting, zoning and the appropriateness of the land use as it relates to the water base and the land base. The issues we will be dealing with in the next five years will include prime farmland preservation, floodplain, zoning, toxics, sediment pollution, integrated programs and program responses.

Future nonpoint implementation efforts will recognize the multiple factors inherent in nonpoint source problems. For example when considering urban runoff pollution control strategies the complications caused by point and combined sewer issues, quantity vs. quality issues aquatic habitat issues, potential stream use issues, the agricultural and urban interface issues and sediment versus water column pollution issue will all have to be integrated into the solution. This conference covers a whole compendium of urban issues. People in water management must try to balance all these aspects of urban issues, and in cases where urban runoff is a component, it should be part of the total control program. This process will have to include cost effective considerations of both point and nonpoint abatement strategies.

In the future any solution to urban runoff or other nonpoint sources of pollution must use an integrated approach which recognizes the stream as a total resource where water quality, water quantity, aquatic habitat, sediment and biota are all considered in the decision making process to ensure that you are managing for the total environment and thus maximizing the use of the water directly or indirectly. In many cases decisions have been made with only one aspect of the resource considered and this has created problems in other portions of the program. The Agency is working with other agencies through the State Water Plan to create a more effective decision making process in the regulatory administrative and policy areas to ensure that the total water resource is the framework for any water resource management program.

URBAN RURAL CONFLICTS WASTE RELATED PROBLEMS

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I would like to discuss water quantity and quality problems which result from conflicts in the urban-rural fringe. However, before proceeding with this discussion, we should define the magnitude of the farmland conversion problem which exists in the nation and the state.

The National Agricultural Lands Study (NALS), the definitive farmland conversion study, was published in January 1981. From 1967 to 1977, NALS indicated that 30.8 million acres of farmland were converted from agricultural use to non-agricultural uses in the nation. The study indicated that Illinois lost approximately 106,000 acres of farmland annually to non-agricultural development during the same time period.

In 1977, the United States had 413 million acres of farmland with high and medium potential for conversion to cropland. Thus the cropland base for the nation was 540 million acres. NALS has estimated that by the year 2000 an additional 77 to 113 million acres of cropland will be needed to meet domestic and export demand. Since only 127 million acres of agricultural land have a high or medium potential for conversion to cropland, development of strategies to protect our farmland base is important.

Most of the development which occurs in states likes Illinois, Iowa, and the other traditional agricultural states occurs on the best farmland in the world. During the 1970's, 40Δ of all houses built in the United States were constructed in rural areas on agricultural land. My discussion today will focus on the spread of urban development into rural areas. Much of what I discuss will be based upon my experience in DeKalb County, Illinois where I was the County Planning Director and Zoning Administrator for 5 1/2 years.

There are numerous water quality and quantity problems when residential development occurs in rural areas. Frequently, subdivision developers do not consider subsurface drainage systems. As a result of field tile disruption farmland which was adequately drained prior to development becomes subject to ponding. The corresponding wetness problems reduce yields and create other operational problems.

In several cases, subdivisions have been constructed in rural areas without adequate stormwater retention facilities. This has created severe flooding and ponding problems in the subdivision and on adjacent farmland. Another problem related to subdivision development is that of soil erosion and sediment control. Quite frequently when subdivisions are under construction, the developers will remove all vegetation and leave the ground in a barren state causing increased erosion and sediment deposition. Most counties in the State of Illinois do not have requirements in their subdivisions ordinances which cover erosion and sediment control. I feel that this is one area in which state government could encourage local units of government to adopt these provisions as part of their regulations.

Septic tank failures are a major problem related to development in rural areas. This is especially true when subdivisions are constructed adjacent to reservoirs which serve as public water supplies. There are several classic examples of reservoirs which were constructed for public water supplies and which have been contaminated as a result of subdivision development around the lake with inadequate septic systems. The Illinois Department of Agriculture and the Illinois Environmental Protection Agency through the Soil and Water Conservation Districts should encourage local units of government to adopt ordinances which regulate soil erosion and sediment control, stormwater retention facilities, and septic tank ordinances.

In the process of developing the State's Long Range Soil and Water Conservation Plan, the Bureau of Farmland Protection developed a system to rank the counties in the state according to the severity of farmland conversion. Five factors were utilized to develop the ranking system. The five factors were: percent of farmland change, 1974-78; rural housing change, 1970-1980; percent prime and important farmland; population change, 1960-80; and popluation per square mile. All 102 counties were ranked for each of the five categories. Each county's scores in each category were added and a new composite score recorded. The counties were then ranked according to their composite score with the lowest number points being considered the most severe in terms of farmland conversion. Based on the formula, the 20 counties with the severest farmland conversion problems in Illinois are: Boone, DeKalb, Kendall, Champaign, Sangamon, Kane, Ogle, Grundy, Henry, Clinton, McHenry, McLean, Coles, Perry, Effingham, LaSalle, Jackson, Woodford, McDonough, and Will County. In most cases, the three most important factors which determined where counties would rank were: percent of farmland change, rural housing change, and percent prime and important farmland. All of the counties that ranked in the top 20 had very high rates of growth for rural housing between 1970 and 1980. Additionally, these counties have a high percentage of their farmland in prime and important land classifications.

The Illinois Department of Agriculture is concerned about farmland conversion in all counties of the State. Determining which counties have the severest conversion problems can aid the Agency in directing its efforts to assist local units of government in developing programs to protect farmland. However, this does not mean that the county which ranks low in terms of priority will not receive assistance from the Department if they wish to develop a program to protect farmland.

SESSION 1-A: NATIONWIDE URBAN RUNOFF PROGRAM (NURP) -- REGIONAL SUMMARIES

SOURCES OF URBAN STORMWATER CONTAMINANTS

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To evaluate the various sources of urban stormwater contaminants, a multi-faceted monitoring program was developed. An aggressive street surface sampling program was maintained at one of each of the paired water quality stations. A total of 554 street surface contaminant samples were collected, including 142 accumulation, 133 street sweeper removal, and 19 rainfall washoff evaluations. In addition, atmospheric wetfall and dryfall monitoring was conducted at eight locations in or nearby the water quality sites. A total of 242 wetfall and 112 dryfall samples were collected. Lastly, rooftop runoff from three houses was monitored, and a total of 48 composite rooftop runoff samples were collected. Through an analysis of stormwater contributions from street surfaces, rooftops, and precipitation, a mass balance of stormwater contaminant sources was achieved.

Most of the sediment and toxic metals in urban runoff originate in washoff from the street surface. However, most of the total phosphorus originates in washoff from areas other than street surfaces. The rooftops were the other major impervious surfaces, but they generated a relatively low amount of most stormwater pollutants. The rooftops in the medium density residential areas contributed less than 15 percent of the stormwater loading values, and the rooftops contributed only about 3 percent of the total event loading in the high density residential areas. Rooftops, however, were an important source of zinc, since zinc concentrations were much higher in the rooftop runoff than in the stormwater. The pollutant concentrations were not measured in the runoff from pervious areas, but the pervious areas only generated runoff during larger events. It was estimated the rainfall should exceed 2.5 inches/hour and 0.5 inches/hour for medium density and high density residential areas, respectively, to generate a signficant (20%) amount of the total runoff from the pervious areas. A signficant amount of some pollutants originated in the precipitation itself. Usually the rainfall contributed between 10 and 20 percent of the suspended solids, total P and total lead stormwater loading values.

STREET SWEEPING EFFECTS ON URBAN STORMWATER QUALITY

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This paper presents findings of a study of street sweeping and urban stormwater quality that was conducted by the Wisconsin Department of Natural Resources as part of the Nationwide Urban Runoff Program.

To evaluate the effects of street sweeping as an urban stormwater management practice, a threefold approach was taken. First, an evaluation of in-situ street sweeper contaminant removal was conducted by sampling street surface contaminants before and after sweeping in four urban watersheds. Secondly, the water quality impacts of street sweeping was evaluated through use of a conventional test and control experiment in four paired (eight total) small urban watersheds. Within each basin pair, one watershed was designated as the test site, and the other the control site. Street sweeping in the control sites was maintained at the usual or baseline frequencies that are normally maintained by the respective municipalities for aesthetic reasons. Street sweeping in the test sites alternated between corresponding baseline frequencies (control periods) and accelerated frequencies (test periods). By comparing the stormwater quality between test and control sites between test and control periods, an evaluation of the waste quality impacts of street sweeping was achieved. Thirdly, a model was developed in this project to extrapolate the findings to other sweeping frequencies. Further, to complement the technical findings of this study, a socio-economic evaluation for street sweeping was also conducted. Lastly, the findings of this study were applied to the area wide water quality planning process for three urban areas.

Street Sweeping Evaluation - Champaign, Illinois NURP

by

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INTRODUCTION

In 1978 the U.S. Environmental Protection Agency (USEPA) concluded that available data concerning characteristics, impacts, and control of urban runoff were inadequate for needs of planning for future development and implementation of policy and programs. To remedy this inadequacy, the agency decided to sponsor a Nationwide Urban Runoff Program (NURP). Projects were selected for 28 locations across the country to represent problems engendered by urban runoff under a variety of influences: hydrologic and climatologic conditions, land use, degree of urbanization, population, and engineering practice. All projects were located in areas which had previously identified urban runoff as a problem in areawide water quality management planning. The major effort in every project was devoted to data collection and interpretation, with special attention given to at least one of three aspects: 1) characterization of problems, including types and loads of pollutants; 2) assessment of impacts on receiving waters; and 3) evaluation of recommended control practices.

A proposal from the Illinois Environmental Protection Agency (IEPA) to test municipal street sweeping as a management practice for urban storm runoff quality was accepted for NURP by USEPA. The interest of IEPA in street sweeping as a control practice was grounded in the 208 Water Quality Management Plan for Illinois. The portion of the state plan dealing with urban stormwater recommended optimization of street sweeping efforts to maximize pollutant reduction in runoff without increasing sweeping costs to a community. The plan acknowledged that development of optimization criteria depended on a more accurate assessment of the effectiveness of street sweeping in reducing runoff pollutant loads. IEPA contracted with the Illinois State Water Survey (ISWS) to perform the three-year study, which was completed in March 1982. Complete results are presented in ISWS Contract Report No. 300, December, 1982.

OBJECTIVE

The primary objective of this project was to evaluate the potential conventional municipal street sweeping as a management practice for the improvement of urban stormwater quality.

METHODOLOGY

Four separately sewered urban drainage basins in Champaign, Illinois, were selected as the study sites, figure 1. The two John Street basins were entirely comprised of single-family residential land use; these had areas of 39 and 55 acres. The Mattis Avenue basins featured multi-family residential and strip commercial land uses; their areas were 16 and 28 acres. Other physical parameters of the basins presented in table 1.

Table 1. Comparison of Physical Basin Parameters

Parameters	Mattis North	Mattis South	John North	John South
Total Area (acres)	16.7	27.6	54.5	39.1
Directly Connected Imperv. Area (% of Total)	58.0	40.0	18.5	17.5
Roadway (% of Total)	26.0	21.0	14.0	13.4
Lane Miles	2.70	3.21	4.79	3.36
Curb Miles	1.15	1.33	4.79	3.36
Supplemental Imperv. Area (% of Total)	3.0	11.0	14.5	14.7
Grassed Area (% of Total)	39.0	49.0	67.0	67.8
Basin Slope (% of Total)	.54	1.2	.67	1.31
Fall (ft)	17.5	29.8	21.9	33.3
Length (ft)	3255.0	2480.0	3260.0	2535.0
Slope 15-85 (% of Total)	.51	1.27	.69	1.52
Fall (ft)	11.6	22.0	15.9	26.9
Length (ft)	2280.0	1735.0	2285.0	1775.0

The outlets of the storm sewer networks in all four basins were instrumented for flow monitoring and water quality sampling. In addition, four rain gages and three wet-dry fallout samplers were operated in the basins. A computer-controlled telemetry network was installed and developed for collection, storage, and management of runoff event data. During storms, rainfall and flow data from the sites were recorded at one-minute intervals. For about half the duration of the project, runoff quality was determined by analyzing discrete samples collected at five-minute intervals throughout the events; the rest of the time, flow-weighted composite samples were collected and analyzed.

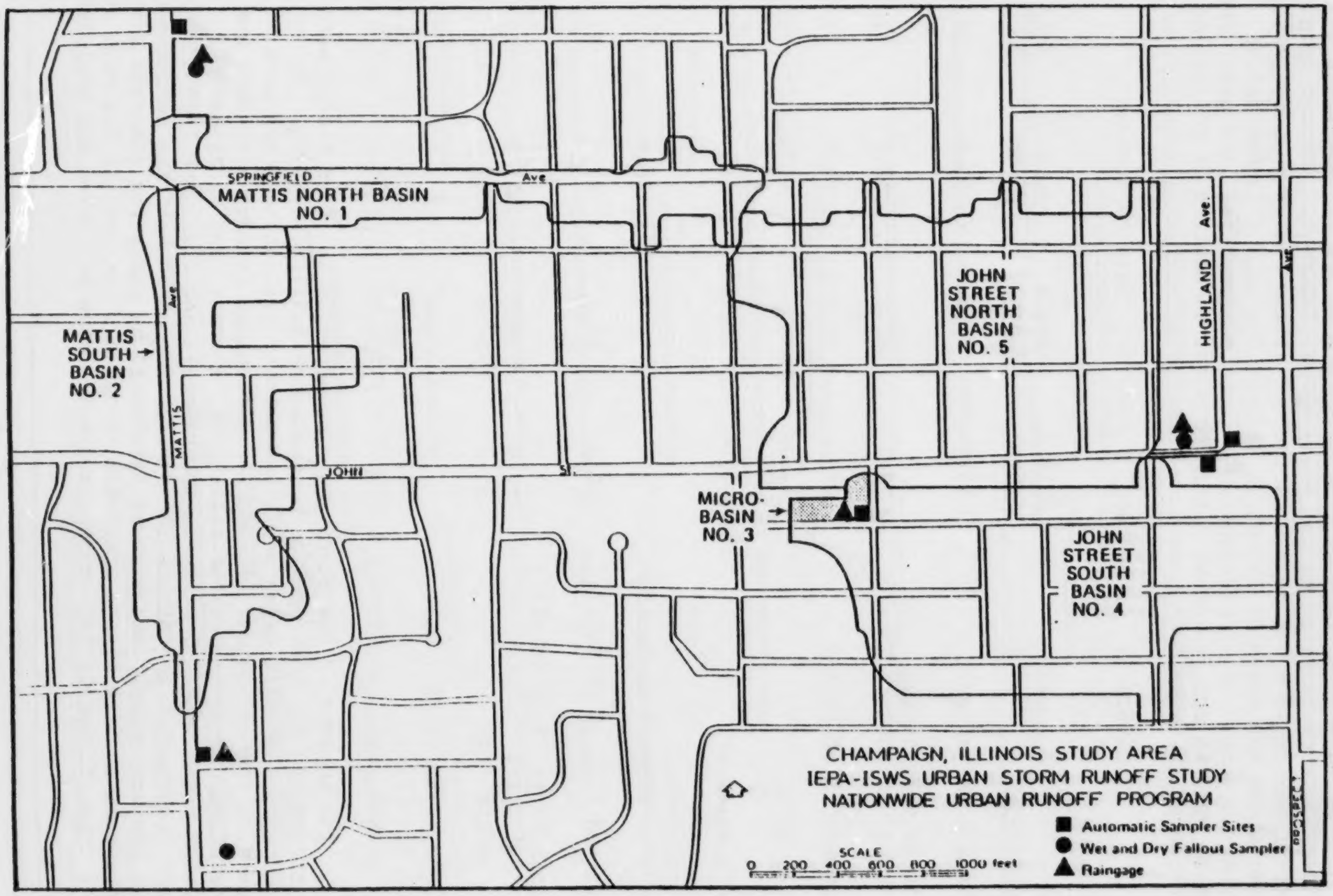
SPRINGFIELD Ave.
MATTIS NORTH BASIN NO. 1
MATTIS SOUTH BASIN NO. 2
MATTIS Ave
JOHN St.
MICRO-BASIN NO. 3
JOHN STREET NORTH BASIN NO. 5
JOHN STREET SOUTH BASIN NO. 4
HIGHLAND Ave.
Ave.
PROSPECT
CHAMPAIGN, ILLINOIS STUDY AREA
IEPA-ISWS URBAN STORM RUNOFF STUDY
NATIONWIDE URBAN RUNOFF PROGRAM
■ Automatic Sampler Sites
● Wet and Dry Fallout Sampler
▲ Raingage
SCALE
0 200 400 600 800 1000 feet

Figure 1. Champaign NURP study area - basin boundaries and instrument locations

Laboratory determinations of concentrations of a variety of constituents, including solids, metals, and nutrients, were made on the runoff samples. In all, 90 storm events were monitored and sampled during the 1980-81 seasons. Rainfall samples for 26 of the events were kept and analyzed.

Municipal street sweeping in the basins during this study was performed by the City of Champaign Department of Public Works. In 1980 there was a period of five months, from early March to mid-July, in which there was no sweeping of any of the basins. Starting in late July, one residential basin (John North) and one commercial basin Mattis South were swept by the city twice each week. The other basins were left unswept. This routine was followed through the remainder of the monitoring season, terminating in mid-November. In 1981, the same two basins were swept once per week during April and May, then left unswept from June to August, after which all data collection was halted. In those last three months of monitoring, the Mattis North basin and the John South basin were swept once per week. The city provided gross weights and samples of the material removed from the basins on sweeping days. The test sweeping frequencies of once and twice per week were chosen to represent probable or reasonable levels of effort from the city for cleaning residential and commercial areas.

STREET DIRT SAMPLING

The assumption was made that street surface dirt was the major source of urban runoff pollutants, as well as the only source controllable by street sweeping. A sampling program designed to measure the loads, particle size distributions, and constituent concentrations by particle size of the material on the streets of the basins was conducted throughout the periods of event monitoring and experimental sweeping. Twice per week on each basin, subsamples of the street load were collected from numerous locations, using a vacuum cleaner mounted in a van. The gross weight of a sample was used to calculate the total street load on a basin for that day. The particle size distribution of the load was determined by passing the dried sample through a series of screens and recording the weight of material retained on each. The similar size fractions of samples from several days for one basin were combined for laboratory analysis of constituent concentrations in each size group. In 1981, on days of sweeping in a basin, the street load was measured both before and after sweeping was done. Throughout the period of monitoring, measurements showed that the amount and variability of street load on the commercial basins were considerably higher than on the residential basins. The particle size distributions of street loads were similar for all basins. There were greater concentrations of metals such as lead in the solids from the commercial basins and greater concentrations of nitrogen and phosphorus in the solids from the residential basins.

Effects of experimental street sweeping were expected to be noticeable in both the street load on the basins and the quality of urban runoff from them. Measurements of street load on swept basins showed a definite improvement due to sweeping, as both the amount and variability of load were substantially reduced when compared to values observed during non sweeping periods for the same basins. The particle size distribution of solids on a basin also changed after a period of regular sweeping; coarse particles became relatively scarcer and fines relatively more abundant. This happened because the mechanical sweeper picks up large particles more effectively than small ones. As a result, regular sweeping removes more newly deposited coarse material than fine material, and the particle size distribution shifts toward the fines.

WATER QUALITY DATA ANALYSIS

For each study basin, washoff loads and event mean concentrations (EMCs) of all available constituents were calculated for all events with reliable flow and water quality data. Initial comparisons of peak observed concentrations from discrete-sampled events showed no reduction of any constituents from swept basins. The washoff loads and EMCs were used in two basic analytical approaches.

In parallel analysis, the data set considered for each pair of basins (residential and commercial) was limited to events where both basins of the pair had reliable data. These events were divided into three groups according to the street sweeping program in force when they occurred: no sweeping on either basin, sweeping on only one basin, and sweeping only on the other. Individual plots for each constituent were drawn with points representing each event's EMC or load from one basin plotted against EMC or load from the other basin. Linear regressions were run on the points grouped by sweeping practice and the resultant lines compared to determine whether for any constituent a reduction of load or EMC was evident from a swept basin. Figure 2 is an example of a plot illustrating EMC values of total suspended solids and lead for the Mattis Avenue basins. A problem with this analytical method was that there was not a great number of data points in each subgroup, since only events with good data on both basins were used, and they in turn were separated by sweeping practice. Furthermore, since there were only two full seasons of data collection, the range of event types in each subgroup was not great. Tables 2 and 3 summarize swept to unswept rations of EMC values for the Mattis and John Street basins. The results of this analysis showed no clear indication of improvement of storm runoff quality associated with the experimental street sweeping.

In series analysis, individual data sets were developed for all four sites, consisting of all events for which there were good flow and water quality records. These included many events for each basin for which there were no good data on the paired basin, which expanded the data sets considerably. In each data set the events were separated again according to sweeping practice. For the two groups of events,

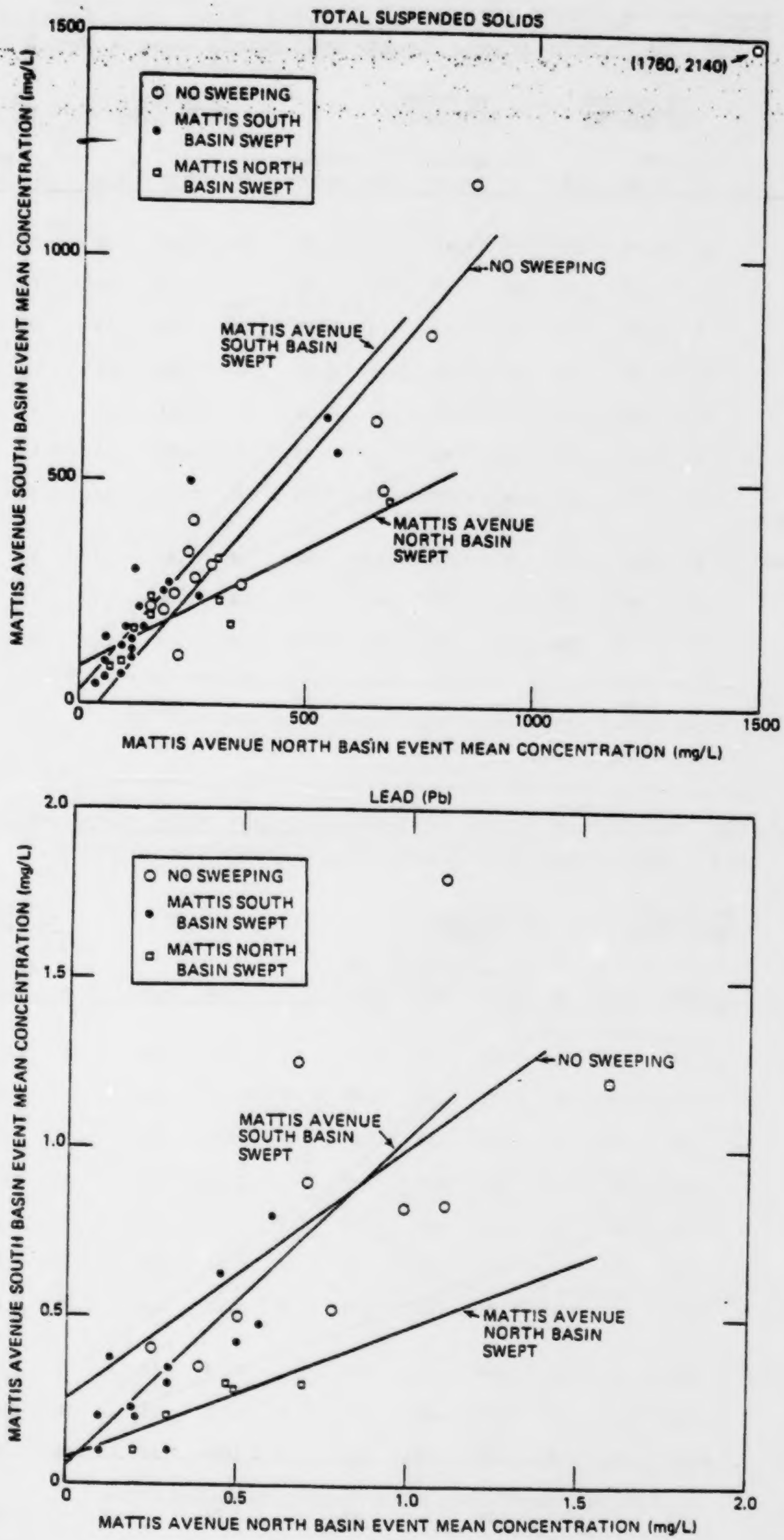

Figure 2. Event mean concentrations for Mattis basins

Table 2. Ratios of Swept to Unswept Event Mean Concentrations for the Mattis Avenue South and Mattis Avenue North Basins

	MS UNSWEPT / MN UNSWEPT			MS SWEPT / MN UNSWEPT				MN UNSWEPT / MS UNSWEPT			MN SWEPT / MS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	13	1.11	.32	19	1.36	.50	1.23	13	1.00	.39	8	1.00	.40	1.00
TDS	13	.93	.34	20	.87	.15	.94	13	1.18	.33	7	1.12	.43	.95
Lead	9	1.28	.73	10	1.14	.43	.89	10	.99	.34	6	1.69	.46	1.71
Copper	11	1.06	.74	11	1.58	2.14	1.49	11	1.29	.69	5	1.37	.53	1.06
Iron	11	1.08	.31	11	1.10	.34	1.02	11	1.01	.31	6	1.57	.66	1.55
COD	9	1.13	.45	8	.88	.16	.78	9	.99	.31	6	1.35	.49	1.36
Nitrate-Nitrite N	9	1.10	.33	9	1.37	1.00	1.25	9	1.02	.44	6	1.17	.71	1.15
Phosphorus	9	1.30	.46	9	1.14	.41	.88	9	.85	.27	6	1.09	.37	1.28
Sulfate	12	1.02	.27	16	.93	.18	.91	12	1.05	.29	7	1.40	.56	1.33
Chloride	12	.79	.26	17	.51	.22	.66	12	1.44	.57	8	2.50	1.18	1.74
G. MEAN		1.07			1.04		.97		1.07			1.38		1.29
S.D.		.16			.34		.24		.16			.37		.28

Table 3. Ratios of Swept to Unswept Event Mean Concentrations for the John Street South and John Street North Basins

	JS UNSWEPT / JN UNSWEPT			JS SWEPT / JN UNSWEPT				JN UNSWEPT / JS UNSWEPT			JN SWEPT / JS UNSWEPT			
	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN	#	MEAN	S.D.	#	ACTUAL MEAN	S.D.	NORMAL MEAN
TSS	7	.74	.25	3	.56	.27	.76	7	1.60	.54	15	1.53	.89	1.02
TDS	7	.98	.19	4	.75	.08	.77	7	1.05	.20	15	.99	.19	.94
Lead	7	.86	.22	3	.78	.38	.91	7	1.03	.28	6	1.59	.62	1.54
Copper	7	.63	.61	3	.58	.27	.92	7	2.72	1.59	6	2.42	2.22	.89
Iron	7	.88	.33	3	.66	.36	.75	7	1.29	.52	7	1.34	.536	1.04
COD	7	.94	.28	3	.78	.28	.83	7	1.25	.36	5	1.30	.12	1.04
Nitrate-Nitrite N	7	1.16	.37	3	1.23	.25	1.06	7	.93	.24	7	.91	.36	.98
Phosphorus	7	.95	.32	3	.86	.11	.91	7	1.18	.47	7	1.09	.44	.92
Sulfate	7	.98	.11	3	.79	.24	.81	7	1.03	.13	15	.94	.16	.91
Chloride	7	1.01	.32	3	.78	.18	.77	7	1.08	.34	16	.99	.51	.92
G. MEAN		.90			.76		.84		1.24			1.24		1.00
S.D.		.16			.17		.10		.39			.39		.16

loads or EMCs of single constituents were fitted to log-normal distributions and the results were plotted. The lines of one of these plots were considered representative of the characteristic washoff load or EMC of a constituent from the basin during periods of sweeping and no sweeping. Figure 3 illustrates these plots using EMC values for total suspended solids and total dissolved solids on Mattis South. The results of this analysis were no more positive than those from parallel analysis. Occasionally improvement in runoff quality appeared to be due to street sweeping, but there was not consistency of results for any constituent for all basins. The load and EMC data were sometimes contradictory for a single basin, with improvement due to sweeping indicated by one plot and not the other. Table 4 summarizes the results of both EMC and load analysis for the Mattis Avenue basins. In summation, there was no clear evidence of reduction of runoff loads attributable to street sweeping.

Summary of Water Quality Results

Table 5 summarizes the swept to unswept ratios for both the John Street basins and the Mattis Avenue basins and for both EMC values and total washoff loads. The series or log-normal results for John South swept have been deleted due to small data sets. The parallel analysis of the John South swept data has been retained, even though it consists of only 3 events. In table 6.13 the basin shown at the head of the column is the swept basin. Under the paired events column the swept basin is compared with its control basin for the same events. Under the log-normal column the swept basin is compared with itself during an unswept period. Geometric means and standard deviations are presented for each basin by type of analysis and for each constituent by EMC and load. The standard deviation presented is the average of the difference between the mean plus one standard deviation and the mean minus one standard deviation.

Looking at the basins individually, John South shows a benefit from sweeping (for three events). John North shows a benefit in the log-normal analysis but degradation in the paired basin analysis. Mattis South shows some benefit for all analyses and Mattis North only shows benefit in the log-normal EMC analysis. Based on the individual constituents, 7 of 10 show benefit from sweeping in the EMC analysis but only 5 of 10 for the load analysis.

In order to better quantify the results, Hypothesis Testing was used to examine the sets of ratios. Logs of the ratios were used to increase the likelihood of a normal distribution. The test statistic used was

$$\frac{T = (\bar{x} - \mu_0)\sqrt{n}}{s}$$

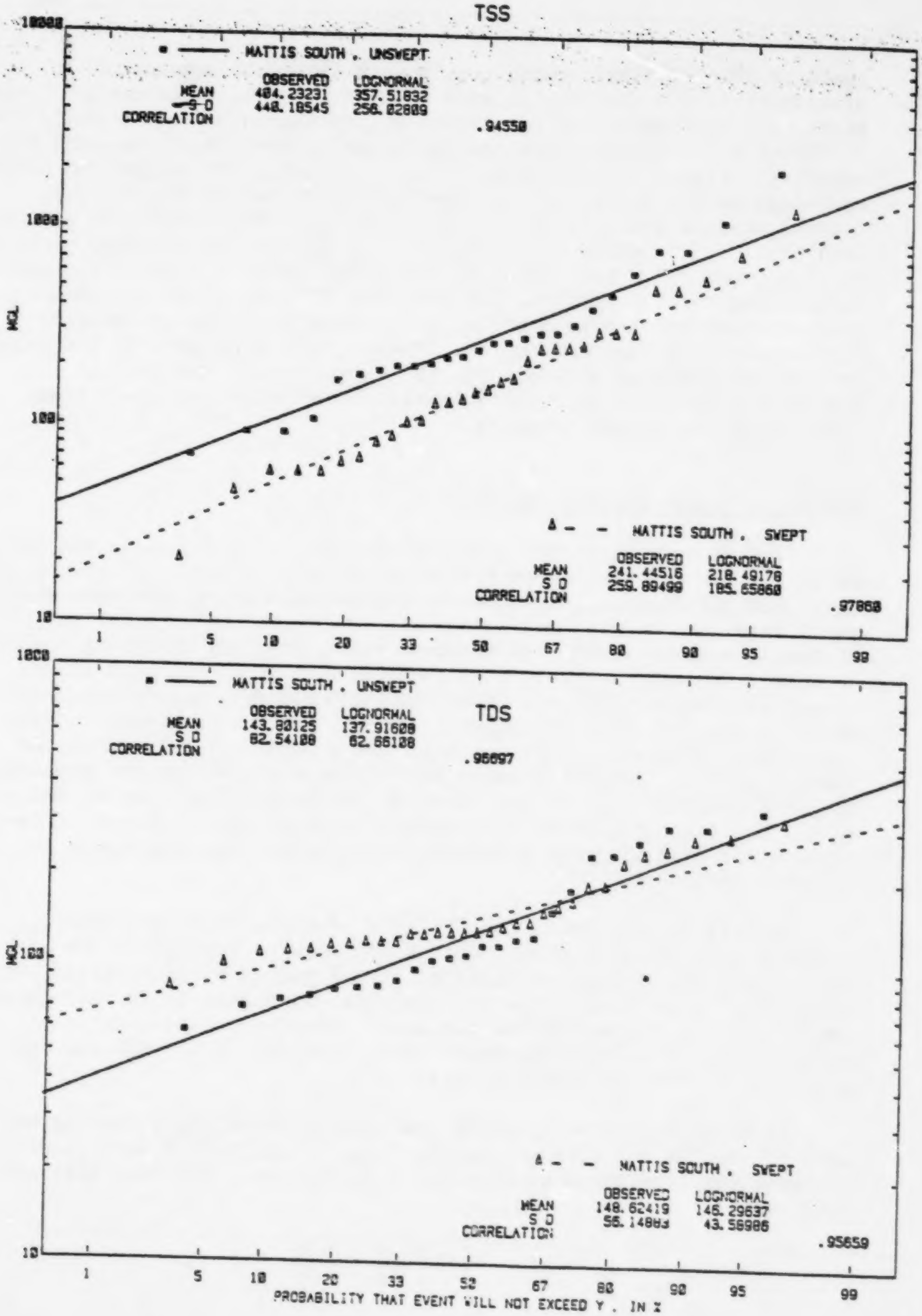

Figure 3. Distribution of EMC values for TSS and TDS - Mattis South basin

Table 4. Ratios of Swept to Unswept EMCs and Loads Using Median Log-Normal Values for Mattis Avenue Basins

	MATTIS SOUTH BASIN		MATTIS NORTH BASIN	
	EMC	LOAD	EMC	LOAD
TSS	.56	.51	.87	1.05
TDS	1.12	.91	.94	1.14
Lead	.50	.47	1.01	1.39
Copper	1.24	1.09	.61	.85
Iron	.52	.50	.93	1.35
COD	.60	.67	.76	1.00
Nitrate-Nitrite N	1.34	1.62	.75	.96
Phosphorus	.76	.76	.82	1.03
Sulfate	1.17	.94	1.15	1.65
Chloride	1.03	.88	.64	.72
G. MEAN	.82	.78	.83	1.18
S.D.	.33	.31	.17	.27

Table 5. Ratios for Swept vs. Unswept Conditions Using Mean Values of EMCs or Total Washoff Loads

CONSTITUENT	JOHN SOUTH				JOHN NORTH				MATTIS SOUTH				MATTIS NORTH				EMC		LOAD	
	PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL		PAIRED EVENTS		LOG NORMAL					
	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	EMC	LOAD	G. MEAN	S.D.	G. MEAN	S.D.
TSS	.76	.56			1.02	1.76	.56	.62	1.23	1.07	.56	.51	1.00	1.57	.87	1.05	.83	.25	.92	.48
TDS	.77	.59			.94	1.66	1.06	1.17	.96	.70	1.12	.91	.95	2.03	.94	1.14	.95	.11	1.12	.45
LEAD	.91	.67			1.54	2.05	.72	.49	.89	1.31	.50	.47	1.71	2.09	1.01	1.39	.96	.42	1.03	.71
CU	.92	.77			.89	1.01	1.90	1.24	1.49	.59	1.24	1.09	1.06	2.90	.61	.85	1.10	.42	1.06	.56
FE	.75	.49			1.04	1.53	.38	.30	1.02	.75	.52	.50	1.55	2.54	.93	1.35	.81	.40	.84	.70
COD	.83	.57			1.04	1.41	.58	.63	.78	.83	.60	.67	1.36	1.54	.76	1.00	.82	.25	.89	.36
NO_2-NO_3	1.06	.76			.98	1.59	1.09	.88	1.25	.84	1.34	1.62	1.15	2.07	.75	.96	1.07	.20	1.16	.47
P	.91	.62			.92	1.31	.87	.70	.88	1.04	.76	.76	1.28	.72	.82	1.03	.91	.15	.85	.23
SO_4	.81	.59			.91	1.61	1.01	1.16	.91	.79	1.17	.94	1.33	1.85	1.15	1.65	1.01	.20	1.14	.50
CL_2	.77	.42			.92	1.00	.85	.85	.66	.65	1.03	.88	1.74	2.65	.64	.72	.89	.31	.87	.52
G. MEAN	.84	.60			1.00	1.46	.82	.74	.97	.83	.82	.78	1.29	1.88	.83	1.08				
S.D.	.10	.11			.16	.34	.37	.34	.24	.21	.33	.31	.28	.76	.17	.27				

where: T = the test statistic

$\bar{x}$ = mean of the logs of the ratios

μ_o = mean of the assumed population

n = number of values

s = standard deviation

μ = true mean of population

The following hypotheses were tested at the 90 percent confidence level:

1. The true mean of the population is less than 1.00
2. The true mean of the population is less than 0.90
3. The true mean of the population is greater than 1.00
4. The true mean of the population is greater than 1.10

Results of the tests at the 90 percent confidence level by basin were as follows:

	True Mean <1.00	True Mean >1.00	Neither
John South	2	0	0
John North	1	1	2
Mattis South	3	0	1
Mattis North	1	3	0

	True Mean <0.90	True Mean >1.10	Neither
John South	2	0	0
John North	0	1	3
Mattis South	0	0	4
Mattis North	0	2	2

Again the results are conflicting. There are 7 data sets below 1, 4 sets above 1, and 3 indeterminant, indicating a slight edge toward sweeping effectiveness. When the test is made more stringent by testing against ratios of .9 and 1.1 (this would amount to a 10 percent decrease or increase in EMC or load), the results change. Under the more stringent test there are 2 data sets below 0.9, 3 above 1.1 and 9 in between. This indicates that there is a 90 percent chance that 2 out of the 14 data sets tested showed EMC or load reduced by 10 percent or more; 3 of the 14 data sets showed EMC or load increased by 10 percent or more; and 9 of the 14 data sets showed changes of less than 10 percent.

A similar analysis of the data by constituent indicates that at the 90 percent confidence level the true mean EMC ratios of TSS, COD and P are less than 1.0 and none are less than 0.9. It further shows that P is the only constituent with a true mean load ratio less than 1.0 and that none are less than 0.9. None of the constituents show EMC or load ratios with true means greater than 1.0 at the 90 percent confidence level.

DISCUSSION

At this time, urban storm runoff remains a water quality problem of indefinite dimensions. Constituent concentrations and runoff flow rates vary rapidly and drastically during events. For many constituents, concentrations well above general use water quality standards may appear in runoff. Yet the appropriateness of the application of such standards to urban runoff is questionable. Standards generally identify limits for continuous, or at least long-duration, constituent levels, but urban runoff is intrinsically intermittent and constituent concentrations are transient. Furthermore, standards customarily refer to constituents in states that are wholly available to assimilation by aquatic life forms, but many constituents in urban runoff are largely associated with solids and are not immediately available for uptake. So while the concentrations and loads of constituents in urban runoff may be substantial, their effect on aquatic life is uncertain. Water quantity rather than quality may be the principal concern in urban streams. The severe fluctuation of water levels in streams conveying urban runoff may have negative influences on aquatic habitats. It may also cause scour and transport of stream bottom materials on occasions of more severe storms. It is possible that water quality effects of urban runoff are not evident until the constituent loads arrive in some receiving water, such as a lake, a reservoir, or a slow-moving larger stream. Deposition of solids loads from runoff could then occur, and constituents associated with the solids could begin to influence aquatic life.

The idea of street sweeping as a management practice for urban storm runoff quality seems sound. If street load is a major source of runoff pollutants, and street sweeping is employed to remove some portion of that load, then some reduction of pollutant concentrations or loads ought to appear in subsequent runoff. In this study the removal of significant portions of street load by sweeping was demonstrated by measuring both the material picked up by the sweeper and the load left on the basin after sweeping. The lack of consequent improvement in runoff quality is a puzzle in which many factors may have a share.

Foremost among these factors is the predominance of fines in runoff solids. The data obtained in this study on particle size in runoff suggest that fines constitute the greatest part of solids in runoff for most events. Mechanical street sweepers are designed to control and collect litter and large material from streets. Their efficiency in collection of fine material is demonstrably low. A vacuum-assisted street sweeper might do a better job of removing fines from streets, but none was available for this study. Another NURP project did test the performance of a vacuum-assisted sweeper, but the results are not known.

Local characteristics of streets, especially condition and texture of the surfaces, may be the limiting factor in sweeper performance. Certainly recommendations can be made for any sweeper or group of sweepers to enhance performance to a maximum. Route layouts, numbers of single or tandem passes, operation criteria, and maintenance schedules can be developed to extract the optimum performance from a machine. Yet irregularities of pavement and curb may undermine the effect of employing such practices. The collection of fines from a rough-textured street with a mechanical sweeper could be very difficult even with the use of optimum sweeping procedures.

Other aspects of sweeping and street load may contribute to the runoff quality problem. Under moderate to heavy street loading conditions, the action of the sweeper may cause the disintegration of larger particles and aggregates into fines which are not collected but are easily washed off. The sweeper brooms may also loosen material adhering to the street, making material available to washoff which otherwise might have remained attached to the street through an event. In either case, the action of the sweeper would be simultaneously to collect solids from the street and to leave behind solids for washoff. Another function of sweeping, which appeared to have occurred on the residential basin in the fall, might be to remove material from the gutter which would otherwise have impeded flow and diminished the load the runoff could carry. With the obstructing material gone from the gutters and inlets, the runoff could carry the remaining solids more freely from the street to the sewer.

It is important to recognize that street load is not the only source of runoff pollutants. Rainfall can supply appreciable fractions of several constituents and nearly all of some, such as ammonia-nitrogen and nitrate nitrite nitrogen. Whether air pollution controls could have a significant impact on reduction of atmospheric contribution is arguable. More would have to be known about individual and nonpoint sources of atmospheric pollutants before any degree of confidence could be reached in plans for controlling them. Directly connected impervious areas other than streets, such as parking lots and some roofs and driveways, will add to storm runoff for most events, though they are rarely sampled or cleaned. Less frequently, other areas such as lawns and roofs which drain onto lawns may also contribute to flows and loads. Local conditions in storm sewers may allow them to serve as sources or sinks of pollutants. Especially in areas of flat terrain, like Champaign, small storms may permit the movement of material form the streets to the sewers, where it may be deposited in the lines or manholes. When this has happened, subsequent larger storms can scour the deposited material from the system and transport it along with new material from the surface. This can increase the difficulty of developing a mass balance of material on a study basin.

Finally it is important to acknowledge the influence of error in measurement on the findings of this study. In a sampling program of this extent the possibilities for error introduction are numerous.

Aspects of event monitoring subject to error include representation of basin rainfall by point rainfall measurement, measurement of runoff water levels, conversion of stage to flow using rating curves, representation of runoff quality with automatic sampling through a fixed intake, and representation of runoff loads by automatically-controlled flow-weighted composite sampling. Possible sources of error in the street dirt sampling program included representation of the load on the pavement by the vacuumed sample and on the basin by the composite of subsamples as dictated by the experimental design, the determination of the particle size distribution of the street load by analysis of one small portion split from the basin sample, and the determination of quality by particle size of load from a basin using composites of several days' worth of samples for each size group. Still other error sources could exist in the street sweeping program as designed by ISWS and practiced by the City of Champaign, including completeness of operation in a basin, accuracy of weighing of load removed from a basin, and representation of the sweeper hopper contents with a single subsample. The cumulative effect of errors in these areas of data collection could have significant impact on the findings. However, ISWS has been diligent in searching for errors and refining summaries, so that the data set developed during the study and the analyses based on it are believed to be the best possible information from the raw data.

CONCLUSIONS

1. Mechanical street sweeping at frequencies as great as twice weekly is not effective in reducing the mean concentration or total load of pollutants in urban stormwater runoff. This conclusion is valid within the constraints of this study which must include the geographical location and its associated weather patterns, the pollutants studied, the type and condition of sweeper, the street surface material and condition, the slope of the street surfaces, traffic volume, and land use. Indications of increases in the concentration or load of pollutants during sweeping were at least as strong as were indications of reduction.

2. Mechanical street sweeping at a frequency equal to or greater than once per week reduces the amount and variability of street dirt. Tests were conducted on asphalt and concrete streets in good condition in four urban basins with two land use types and three general loading ranges. After a period of sweeping at a given frequency, the particle size distribution of the street load in an area will gradually shift toward a greater fraction of fines and a smaller fraction of coarse material.

3. The mechanical street sweeper used in this study demonstrated an overall removal efficiency ranging from 30 to 67%. The effectiveness of street cleaning with a mechanical sweeper depends not only on the operation of the machine but also on the load and particle size distribution of material on the street before sweeping. A mechanical

sweeper generally performs more efficiently in removing coarse material than fine material, though performance depends on the total and relative amounts of each in the initial load. For any urban area, a frequency of sweeping can be determined beyond which additional sweeping effort will not produce any further reduction of street load.

4. Wet deposition is apparently the major source of several constituents of concern in urban runoff. Rainfall contributions may account for 64-100% of ammonia-nitrogen, 33-52% of nitrate-nitrite nitrogen, and 33-67% of copper concentrations seen in storm runoff. For other constituents the portions of runoff concentrations attributable to rainfall are smaller: 6-15% of lead, 2-4% of phosphorus, and 1-2% of iron. For any constituent, the fraction of total runoff loads conveyed into the urban area by precipitation cannot be controlled by any management practice except treatment.

5. In all four basins the greatest percentage of total street load, if the gross material larger than 2000 is excluded, falls in the size range 250-500. For the constituents of major interest, concentrations in size groups below 1000 tend to increase with decreasing size, reaching a maximum in the 63-125 group and falling off in the fines. Combination of these two sets of data shows that the greatest part of the load of a constituent in the total street load exists in the 250-1000 material. Removal of particles in these size ranges would control the bulk of the load of most constituents of concern.

6. Virtually 100% of the ammonia-nitrogen and nitrate-nitrite nitrogen in storm runoff is dissolved and has no apparent relationship with solids. For other constituents the dissolved fraction is less: Kjeldahl nitrogen, 69%; phosphorus, 43%; copper, 32%; manganese, 27%; iron, 2%. Lead and nickel appear to be wholly associated with solids.

AN EVALUATION OF THE WATER QUALITY EFFECTS OF DETENTION STORAGE AND SOURCE CONTROL - NORTHEASTERN ILLINOIS PLANNING COMMISSION'S NATIONWIDE URBAN RUNOFF PROGRAM

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INTRODUCTION

In 1978 the U.S. Environmental Protection Agency initiated the Nationwide Urban Runoff Program (NURP). NURP was designed to provide the concrete answers to the question of the role of urban stormwater in contributing to the degradation of our streams, rivers and lakes. The 208 planning process had identified urban stormwater as a major obstacle to attaining desired stream uses but dealt mostly with generalities especially in the areas of effective management practices and urban stormwater impacts on receiving waters.

To provide more specific answers, 28 demonstration projects were funded under NURP to define the character of urban stormwater, the effectivenss of various control strategies and the impact of stormwater in preventing the most beneficial uses of our nation's waters. The Northeastern Illinois Planning Commission's NURP project focused on the sources of stormwater pollutants and the ability to control these pollutants at their sources and on wet-bottom detention storage as a means for settling pollutants from urban stormwater before they reach a receiving stream.

SITE

An urban lake, Lake Ellyn, in Glen Ellyn, Illinois, some 15 miles west of Chicago, was selected as the study site. Figure 1 shows the lake and its watershed. The 534 acre drainage area is actually divided into three sub-areas (see Figure 1) by Glen Ellyn's storm sewer system to Lake Ellyn. The Main watershed is 390 acres in size and includes all of the older Glen Ellyn commerical district. The remainder of this watershed is residential and institutional. The Linden watershed covers 95 acres and contains all residential and institutional land use. The remaining 49 acre tributary area includes roadways and a park surrounding the Lake, as well as a high school and its grounds. The watershed is well vegetated with little apparent soil erosion. Thirty-three percent of the watershed is under tree canopy during the growing season. Streets are in generally good repair and are traversed by about 2,700 vehicles per day.

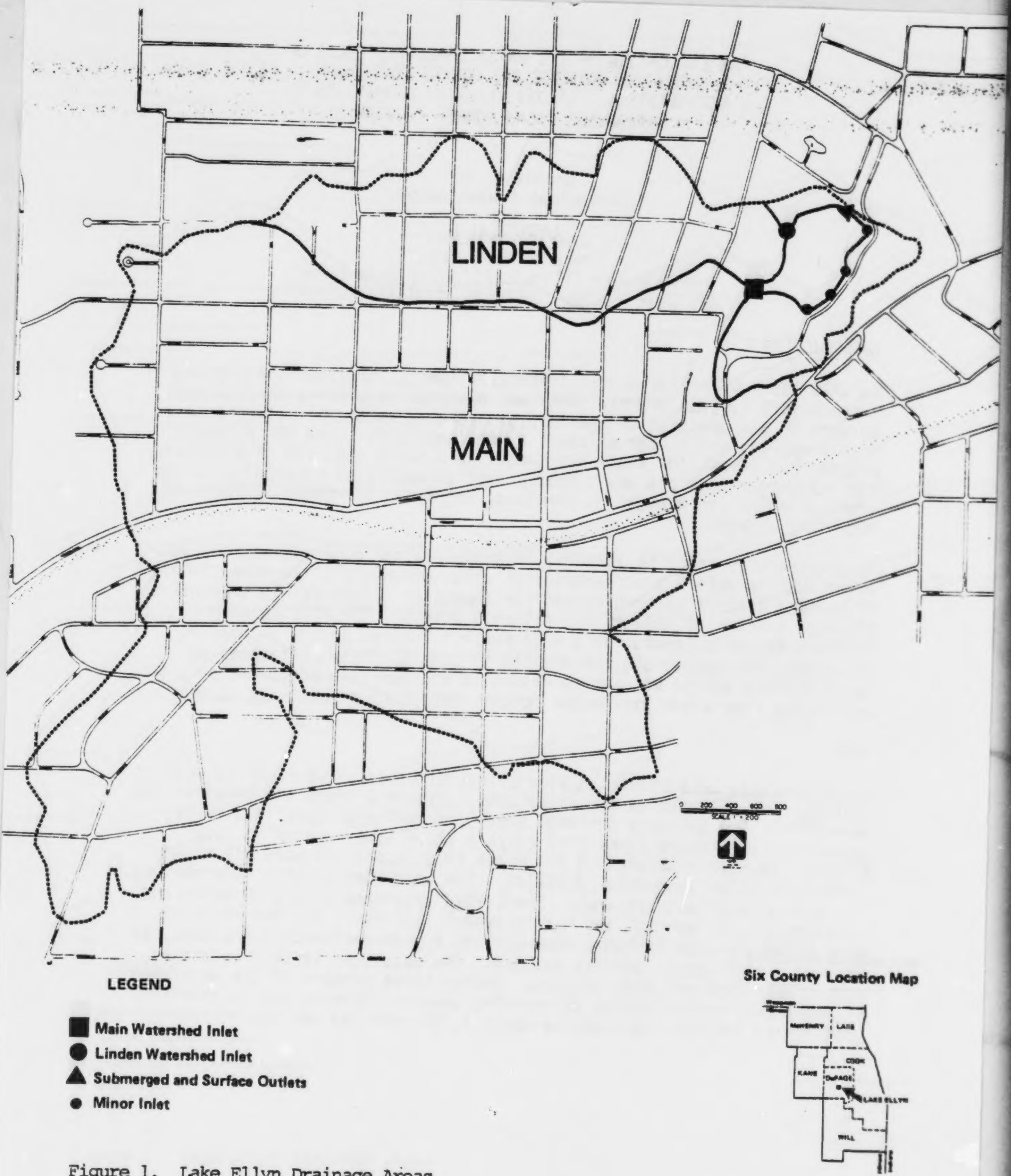

LINDEN
MAIN
0 200 400 600 800
SCALE 1" = 200'
LEGEND
■ Main Watershed Inlet
● Linden Watershed Inlet
▲ Submerged and Surface Outlets
• Minor Inlet
Six County Location Map
McHENRY
LAKE
KANE
COOK
DuPAGE
LAKE ELLYN
WILL

Figure 1. Lake Ellyn Drainage Areas

The watershed is moderately sloped (0.04 feet per foot) with glacial features dominating its topography. The soils are not highly erodible, composed principally of Markham-Ashkum Urban. Approximately 4,200 people live in the watershed. Eighty percent of the land cover is low density single family residential, three percent is high density residential, and ten percent is commercial and institutional. The remaining seven percent is open land and water. Curb and gutters and storm drains provide for stormwater removal for over 95 percent of the watershed. There are 250 catch basins associated with the storm drains.

Lake Ellyn was constructed by damming a small tributary to the East Branch of the DuPage River. Artesian springs which fed the tributary dried up a long time ago and the remainder of the stream was replaced by the present storm sewer system to improve drainage. The Lake is 10 acres in the Main inlet and the Linden inlet. Several minor inlets surround the area and average 4.5 feet deep. The two main sources of stormwater are the Main inlet and the Linden inlet. Several minor inlets surround the lake but contribute little runoff. Outflow from the lake is controlled by two weirs housed in a common structure. One weir is fixed and controls surface overflow. The second weir is adjustable and controls flow from a culvert at the bottom of the lake.

MONITORING PROGRAMS

Project monitoring programs were designed to define the major sources, measure the materials transported by stormwater, and track the movement of these materials through the watershed, as well as into and through the lake. Figure 2 shows the monitoring scheme which was implemented. The input sources were divided into nine generic categories: the atmospheric, traffic, domestic chemicals, animals, vegetation, pavement decomposition, decomposition of building materials, soils, and public works chemicals. The movement of materials through the watershed was monitored at five locations termed control points: roofs, pervious areas, streets, catch basins and the lake. Material budgets were prepared for each point. The summation of the material budgets around these five control points was termed the Lake Ellyn Watershed Materials Budget. The summation of the mass budgets around Lake Ellyn, streets, and catch basins was termed the Transport System Budget because it represented a balance around points from which a pollutant was most likely to be transported to a receiving water.

Table 1 shows the different surveys undertaken to characterize the constituent mass budgets. The survey period was July 1, 1980 to June 30, 1981. Direct measurements of sources was often either impractical or impossible as in the case of traffic, pavement decomposition, animals and the decomposition of buiding materials. Information on these items was gathered through observations and a questionnaire. Constituent quantities from these sources were calculated through balances around control points and checked by independent estimates. For example, traffic inputs were estimated from parkway soils and street dirt constituent loads and were checked using traffic counts and estimated traffic loading rates.

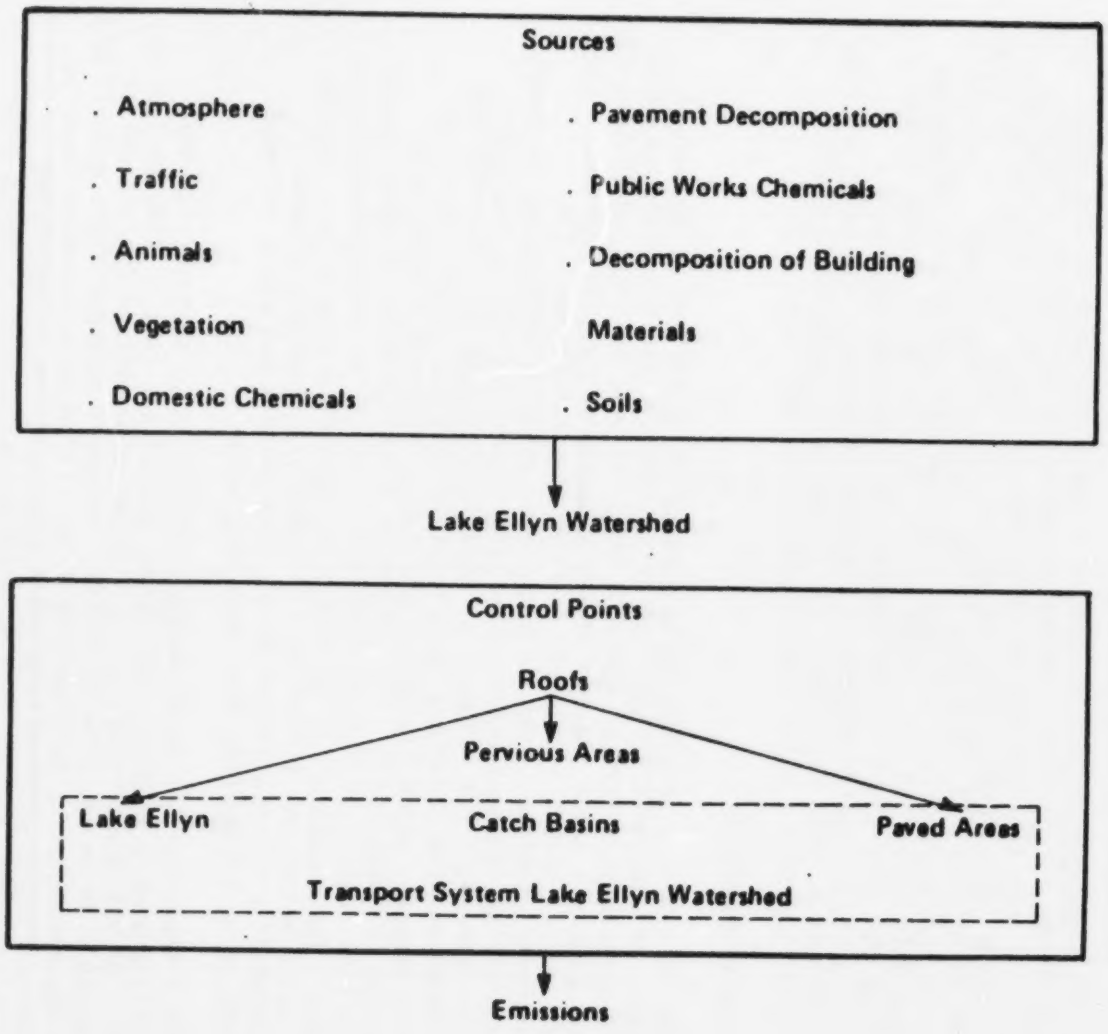

Sources
. Atmosphere
. Traffic
. Animals
. Vegetation
. Domestic Chemicals
. Pavement Decomposition
. Public Works Chemicals
. Decomposition of Building
Materials
. Soils
Lake Ellyn Watershed
Control Points
Roofs
Pervious Areas
Lake Ellyn
Catch Basins
Paved Areas
Transport System Lake Ellyn Watershed
Emissions

Figure 2. Sources, Control Points and the Lake Ellyn Watershed

Table 1. Monitoring Programs

	Interval	Means
Atmosphere		
Precipitation	Weekly	Measured
Dry Fall	Weekly	Measured
Traffic Volume	Annually	Measured
Domestic Chemical Usage	Annually	Questionnaire
Animals	Annually	Questionnaire
Vegetation	Annually	Aerial Photographs, Survey, Measured
Pavement and Construction Decomposition	Annually	Measured, Estimated
Soils	Semi-Annually	Measured
Public Works Chemical Usage	Annually	Measured
Roofs		
Surfaces	Annually	Survey
Washoff	Semi-Annually	Measured
Streets		
Surfaces	Annually	Survey
Road Dirt	Quarterly	Measured
Snow	Annually	Measured
Catch Basins		
Volume	Annually	Survey
Residual Material	Annually	Measured
Lake		
Inflow/Outflow		
Storm	17 Events	Measured
Baseflow	6 Events	Measured
Insitu Water	Quarterly	Measured
Sediment	Quarterly	Measured

The frequency of data collection among the monitoring points was variable. In some cases, such as the domestic use of chemicals, a one-time survey was used to estimate the magnitude of materials resulting from this activity. On the other hand, the concentrations and loads of materials entering the lake during periods of stormwater runoff were measured every 15 minutes for 12 events. Composites were collected for the other 5 events during the study year.

HYDROLOGY

Ninety-five storms occurred during the study year, depositing 38.0 inches of water. The mean storm, for the period, deposited 0.4 inches and had a duration of 4.05 hours. The time between storms was 87.1 hours. Based on 13 years of data from a nearby gauge, the mean precipitation is 35.6 inches per year deposited by 100 storms per year. The long-term, mean event deposited 0.34 inches and lasted for 4.56 hours. The mean dry period was 83.2 hours (see Table 2).

The Lake Ellyn watershed water budget for the study year is shown in Table 3. The water budget shows that although 57 percent of Lake Ellyn's water comes from stormflow another 38 percent comes from baseflow, principally groundwater infiltration and water supply leakage. Seventy-one percent of inflow to Lake Ellyn occurs during the spring and summer (April 1 through September 30). The total yield of the watershed for the study period was 12.6 inches or 33 percent of precipitation. Of this amount surface runoff yield was 7.6 inches (34.3 inches from impervious area and 2.7 inches from pervious area) and baseflow yield was 5 inches.

CONCLUSIONS

Stormwater Constituents

If the influent to Lake Ellyn is characteristic of urban stormwater runoff and violations of state water quality criteria is used to define a problem, only total phosphorus, total lead and total copper concentrations are cause for concern. Table 4 shows statistics for key constituents in both influent and effluent stormwater for Lake Ellyn. On average, phosphorus exceeds the State of Illinois' water quality criteria by 860 percent, copper by 105 percent and lead by 124 percent. These and all of the other constituent, event mean concentrations were found to be well below lethal thresholds. When considering the bioavailability of the contaminants, as would be represented by their dissolved fractions, urban stormwater poses no detectable threat to aquatic life. Further, if urban stormwater were characterized by the effluent from Lake Ellyn, the margin of safety would be substantially increased. Whether dissolved or total, none of the observed effluent constituent concentrations, except for phosphours, exceed the state's criteria and they are substantially below toxic thresholds.

Table 2.--Precipitation Conditions

	Study Year[a]	Long-Term Regional[b]
Mean (inches/year)	38.0	35.6
Storm Frequency per Year[c]	95	99.7
Mean Storm (inches)	0.40	.34
Mean Storm Duration (hours)	4.05	4.56
Mean Intra-Storm Duration (hours)	87.11	83.2

[a] Study year (July 1, 1980 through June 30, 1981)

[b] Thirteen year period (1964-76), O'Hare Airport

[c] A storm is defined by one or more conservative hours having total precipitation 0.04 inches, with one hour without precipation being the end of a storm

Table 3.—Water Budget (acre-feet)[a]

	Summer	Fall	Winter	Spring	Total	Percent
Input						
Stormflow	128	37.4	25.3	148	339	57
Baseflow	51.1	53.5	50.9	69.7	225	38
Precipitation	12.3	4.50	0.18	9.23	26.2	5
Total	192	95.4	76.4	227	591	
Output						
Evaporation	11.8	4.24	4.00	10.6	30.6	5
Stormflow	142	42.0	25.5	158	367	62
Baseflow	38.2	49.3	46.9	58.8	193	33
Total	192	95.5	76.4	227	591	
Percent	33	16	13	38	100	

[a] For study year

Table 4. Event Mean Concentrations (mg/l)

Constituent	Precipitation	Inlet[a] Stormflow	Lake Water Column	Outlet[a] Stormflow
TSS	3.0	196	20.1	19.9
Cl	0.26	34.7	85.2	103
BOD_5	n.d.	18.0	13.0	7.0
NH_4	0.42	0.18	0.40	0.20
P	0.03	0.48	0.20	0.20
DP	0.03	0.08	0.05	0.03
Cu	0.006	0.041	0.010	0.006
Pb	0.014	0.224	< 0.11	0.024
Zn	0.051	0.171	0.028	0.028

[a] Geometric Mean

Constituent Sources

Table 5 summarizes constituent loads to the Lake Ellyn watershed and its transport system, highlighting the principal sources and their relative contribution. Atmospheric deposition, both precipitation and dryfall, contributes 25 percent of the total zinc entering the watershed and 23 percent of the zinc reaching the transport system. Atmospheric deposition also contributes 21 percent of the total copper to the watershed. Fifty percent of the total copper, 84 percent of the total lead, and 21 percent of the total zinc are contributed to the watershed by traffic. Most of the copper probably comes from brake lining wear, most of the lead from gasoline combustion exhaust, and most of the zinc from tire wear. Traffic also contributes 61 percent of the copper, 88 percent of the lead and 28 percent of the zinc reaching the transport system. The decomposition of streets, parking lots, driveways and curbs is a significant source of total solids, contributing 10 percent of the load to the watershed and 20 perecent of the load enterng the transport system. While heavy metals are present in paving material they are not found in significant quantities.

The direct application of fertilizers and de-icing chemicals are largely responsible for the phosphorus and chloride loads, respectively. Fertilizer applicatons contribute 27 percent of the total phosphorus to the watershed and 17 percent of the load to the transport system. Street salting is responsible for 12 percent of the total solids reaching the watershed and virtually all of the chloride. Twenty-four percent of the total solids reaching the transport system come from street salting. Domestic and wild animals are responsible for 14 percent of total watershed phosphorus and 23 percent of the phosphorus reaching the transport system. Most of this load is from wild animals (birds, squirrels and rabbits). Migratory birds contribute most of the phoshorus load from animals to Lake Ellyn. Vegetation is the prinicpal source of solids in the watershed. It is also the principal source of total phosphorus and a significant source of copper. The influence of vegetation on the loads reaching the transport system is somewhat less. It is responsible for 18 percent of total solids and 43 percent of total phosphorus. Soils, either through erosion by surface runoff or shallow groundwater and baseflow, contribute 16 percent of the total solids to the watershed. They are the number one source, however, of solids moving to the transport system. The decomposition of building materials (i.e. gutters, paint, shingles) can and do contribute constituents to the watershed. In fact, it is the principal source of zinc to the watershed and to the transport system.

Control Points

Roofs

Total solids, phosphorus and metals are entrained in runoff from roofs. Concentrations are about an order of magnitude higher (TS 97.7 ppm, TP 0.41 ppm, Cu 0.06 ppm, Pb 0.10 ppm, Zn 0.33 ppm) than found in precipitation. The zinc concentration in roof runoff is twice as high

Table 5. Principal Constituent Sources

	Lake Ellyn Watershed			Lake Ellyn Transport System		
Constituent	Principal Sources	Percent	Unit Load (lbs/acre/yr)	Principal Sources	Percent	Unit Load (lbs/acre/yr)
Total Solids	Vegetation	55	3600.0	Soils	31	1070.0
	Soils	16	1070.0	Street Salting	24	816.0
	Street Salting	12	820.0	Pavement Decomposition	20	676.0
	Pavement	10	57.0			
Chloride	Street Salting	93	490.0	Street Salting	> 99	490.0
Phosphorus	Vegetation	54	9.9	Vegetation	43	6.9
	Fertilizer Application	27	4.9	Animals	23	3.3
	Animals	14	2.4	Fertilizer Application	17	2.8
Copper	Traffic	50	0.20	Traffic	61	0.08
	Vegetation	16	0.06	Soils	12	0.02
	Atmosphere	14	0.06			
Lead	Traffic	84	1.87	Traffic	88	1.00
Zinc	Construction Material Decomposition	34	0.52	Construction Material Decomposition	29	0.17
	Atmosphere	25	0.47	Traffic	28	0.16
	Traffic	21	0.32	Atmosphere	23	0.14

(0.330 ppm) as that found in stormwater runoff to Lake Ellyn (0.171 ppm). Other constituent concentrations are similar between roof runoff and stormwater to the lake. Roof runoff transports 39 percent of total watershed zinc. It is interesting to note that concentrations of total phosphorus, total copper, and total lead in roof runoff are at or exceed the State's water quality criteria. Concentrations of the other constituents do not exceed these criteria.

Pervious Surfaces

Pervious surfaces receive significant inputs of metals from traffic. Metal concentrations found in snow on parkways near curbs are 20 to 400 times higher than concentrations in snow away from traffic influences. Chloride concentrations are 150 to 500 times higher and total solids concentrations 30 to 80 times higher. Total phosphorus concentrations are 20 to 60 times higher. Total phosphorus concentrations ae 20 to 60 times higher. A marked increase in constituent concentrations in curbside snow was noted with increasing traffic volume, indicating the importance of traffic in constituent deposition. The principal sources of solids to pervious areas are vegetation (1,790,000 lbs/year) and displaced road dirt (269,000 lbs/year). Roof runoff contributes most of the total zinc to pervious areas (207 lbs/year). The removal of grass clippings and leaves through regular litter pickup is an important activity since nearly three-quarters of all solids reaching pervious areas are controlled by this means. Over 90 percent of the phosphorus load to pervious areas is controlled by grass and leaf collections.

Streets and Parking Areas

Most of the solids reaching streets and parking areas from pervious runoff (41 percent or 510,000 lbs/year) and street salting (22 percent or 278,000 lbs/year). Street salting is the only significant source of chloride (168,000 lbs/year). The principal source of phosphorus is pervious runoff (270 lbs/year). Traffic is the principal source of metals.

Stormwater runoff impacts both the quantity and the particle size distribution of road dirt. Typically, runoff from the Lake Ellyn watershed has enough energy to move particles less than 500u but not enough to move particles above that size. Both the load and relative percentage of material greater than 500u on streets were more likely to increase than decrease as a result of runoff. Road dirt loads increase in the absence of rainfall or street sweeping. Particles less than 63u were found to increase more rapidly than other sizes in the absence of rainfall or sweeping. The distribution of particle sizes found in the Lake Ellyn Watershed is shown in Figure 3.

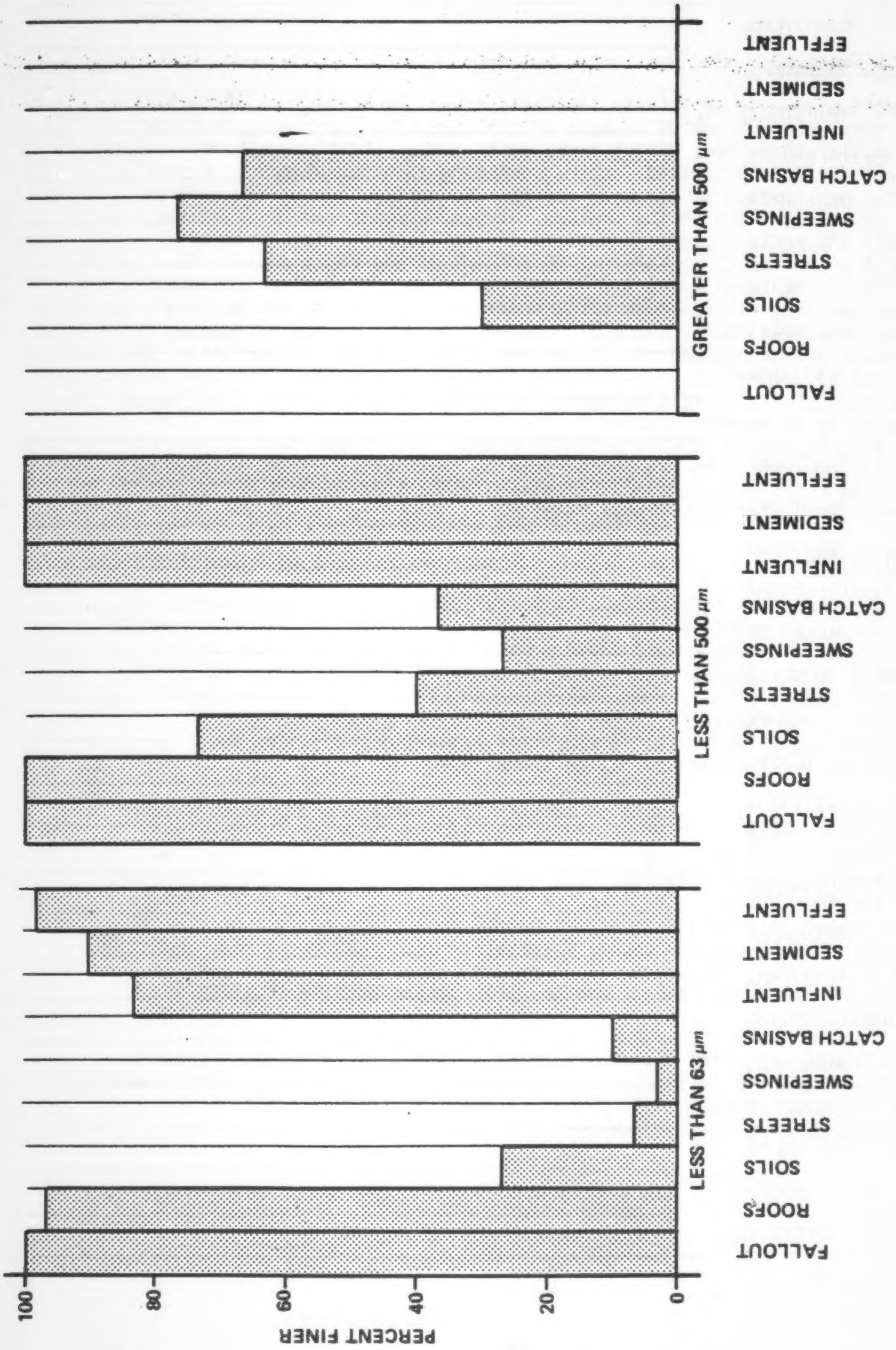


Figure 3. Particle Size Distribution

Street Sweeping

Street sweeping is relatively ineffective for the collection of particles less than 500u. Since 99 percent of the particles entering Lake Ellyn are smaller than 500u, street sweeping is not an effective control measure for this watershed. Street sweeping is also subject to climatic limitations imposed by frequent rainfall in spring, summer and fall as well as snow and ice in the winter. Street sweeping removes from the streets and parking areas 46 percent of the total solids, about 16 percent of the total phosphorus, 30 percent of the total copper, 52 percent of the total lead, and 46 percent of the total zinc. However, street sweeping removes from these areas only 11 percent of the total solids less than 500u (Figure 3). Correspondingly, sweeping removes only 8 percent of the phosphorus, 15 percent of the copper, 26 percent of the lead and 23 percent of the zinc associated with particles less than 500u, those most likely to be transported by runoff to Lake Ellyn. The impact of sweeping is further reduced by the fact that not all material less than 500u is washed away by a runoff event. This means that although sweeping removes particles which could be transported, it might have no effect on event pollutant concentrations since a sufficient reservoir of material less than 500u always remains.

Catch Basins

Based on their low trap efficiency for all constituents catch basins in the Lake Ellyn watershed are not a viable control strategy. Catch basins in the Lake Ellyn watershed capture about six percent of total solids reaching them. They trap about 10 percent of influent suspended solids; however, catch basins remove only about two to five percent of the phosphorus and metals in street washoff. Based on the measured accumulations of materials in catch basins during the study, about 10 percent of their volume is filled annually.

Catch basin sludge was found to contain fewer metals and phosphorus than Lake Ellyn sediment. Catch basin sludge is very similar, in particle size distribution and constitutent concentrations, to road dirt. The constituent concentrations of lake sediment are similar to those of road dirt for the particle size fraction less than 63u. Although 95 percent of the material washed from the streets to catch basins is less than 500u in size, only 35 percent of the material in catch basins is less than 500u (Figure 3). Therefore, it is apparent that smaller particles are moving off street surfaces, through catch basins and are settling in Lake Ellyn.

Catch basins may serve a useful purpose by trapping larger particles (>500u). In these instances, catch basins may serve to keep storm sewers from clogging. However, the preferred control strategy would be to eliminate erosion to storm sewers.

Detention

Detention storage, as provided by Lake Ellyn, modifies constituent concentrations and, in most cases, removes and immobilizes constituent materials. Exce~~pt~~ for chloride and ammonia, the means of all reported constituents were substantially reduced as shown in Table 4. This reduction ranged from a factor of two to over one order of magnitude. Chloride concentrations in the lake increased during the winter months and during the spring the effluent concentrations often exceeded the influent concentrations, the maximum influent concentration was 86.0 mg/l while the maximum effluent concentration was 224 mg/l. Nitrates are being converted to elemental nitrogen and organic material is being converted to ammonia in the lake; as a result, effluent nitrate concentrations are lower than influent concentrations and the reverse is true for ammonia. The maximum influent concentration of ammonia was 0.83 mg/l while the maxium concentration of ammonia in the effluent was observed to be 1.24 mg/l.

On an annual basis, the trap efficiency of Lake Ellyn ranges from +0.90 for nitrate and nitrite to -1.32 for dissolved lead (see Table 6). The trap efficiency, in part, relates to the physical characteristics of the constituent, whether it is in the dissolved or solid state, and to chemical transformations within the lake. Those constituents adsorbed to suspended solids or in the solid state have higher trap efficiencies, generally, than those constituents in the dissolved state. Such dissolved constituents as chloride tend not to accumulate in the lake and are moved in and out on a seasonal basis. Nitrates and nitrites are desposited with solid materials and then converted to elemental nitrogen due to the anoxic conditions found at the bottom of the lake. This results in high trap efficiency relative to nitrates and nitrites. The decomposition of organic material adds ammonia leading to a low trap efficiency, -0.56 for this constituent. Some 87 percent of the total lead is trapped by the lake, however, part of this load is returned to the water column through chemical complexing with chloride. Consequently, the trap efficiency of Lake Ellyn relative to dissolved lead is a -1.32, (i.e., 132 percent more dissolved lead leaves Lake Ellyn than enters it). Other than for chloride, ammonia and dissolved lead, the constituent trap efficiencies were positive ranging from 0.14 for total organic carbon and 0.25 for BOD_5 through 0.6 for total phosphorus to 0.78 for zinc, 0.81 for copper, and 0.87 for total suspended solids.

Over 96 percent of the solids entering Lake Ellyn are delivered through baseflow (58 percent) or stormflow (38 percent) as shown in Table 7. Ninety-nine percent of the solids in baseflow are dissolved. About 50 percent of the solids in stormwater are dissolved. Virtually all of the suspended solids entering the lake in baseflow and over 83 percent of the suspended solids in stormflow are less than 63u in diameter. Almost all of the solids in stormflow are less than 500u in diameter. Suspended solids leaving the lake either in baseflow or stormflow are virtually all less than 63u in diameter.

Table 6. Trap Efficiency

Constituent	Storm[a]	Study Year[b]
TSS	0.90	0.87
Cl	-1.82	-0.33
COD	0.50	0.45
BOD_5	0.58	0.25
TOC	0.32	0.14
NH_4	-0.69	-0.56
NO_2-NO_3	0.84	0.90
P	0.51	0.60
DP	0.56	0.72
Cu	0.84	0.81
Pb	0.89	0.87
DPb	-1.86	-1.32
Zn	0.84	0.78

[a] Based on 14 measured events and a total of 91 storm events

[b] July 1, 1980 through June 30, 1981

Table 7. Lake Ellyn Materials Budget (Loads in Pounds)

	Total Solids	Solids < 63u	Solids 63-500u	Solids > 500u	Cl	P	Cu	Pb	Zn
LOADS IN									
Roof Runoff	9,250	8,920	330	---	208	14.2	1.9	5.1	50.5
Stormwater	363,000	331,000	32,000	---	40,600	388	36.3	212	112
Baseflow	558,000	557,000	1,000	---	95,400	300	3.7	3.0	15.0
Vegetation	21,000	20,000	1,000	---	85	28.5	0.3	0.5	0.7
Animals	411	411	---	---	---	14.2	---	---	---
Precipitation	1,610	1,610	---	---	16	1.3	0.4	0.9	2.6
Dryfall	1,200	1,200	---	---	16	5.6	0.2	0.6	1.1
Total	954,000	920,000	34,000	---	136,000	752	42.8	222	182
LOADS OUT									
Stormwater	449,000	448,000	1,000	---	115,000	197	5.99	22.8	26.8
Baseflow	254,000	254,000	---	---	66,000	83.8	2.09	6.40	9.95
Total	703,000	702,000	1,000	---	181,000	281	8.10	29.2	36.8
ACCUMULATION	251,000	218,000	33,000	---	-45,000	471	34.7	193	145

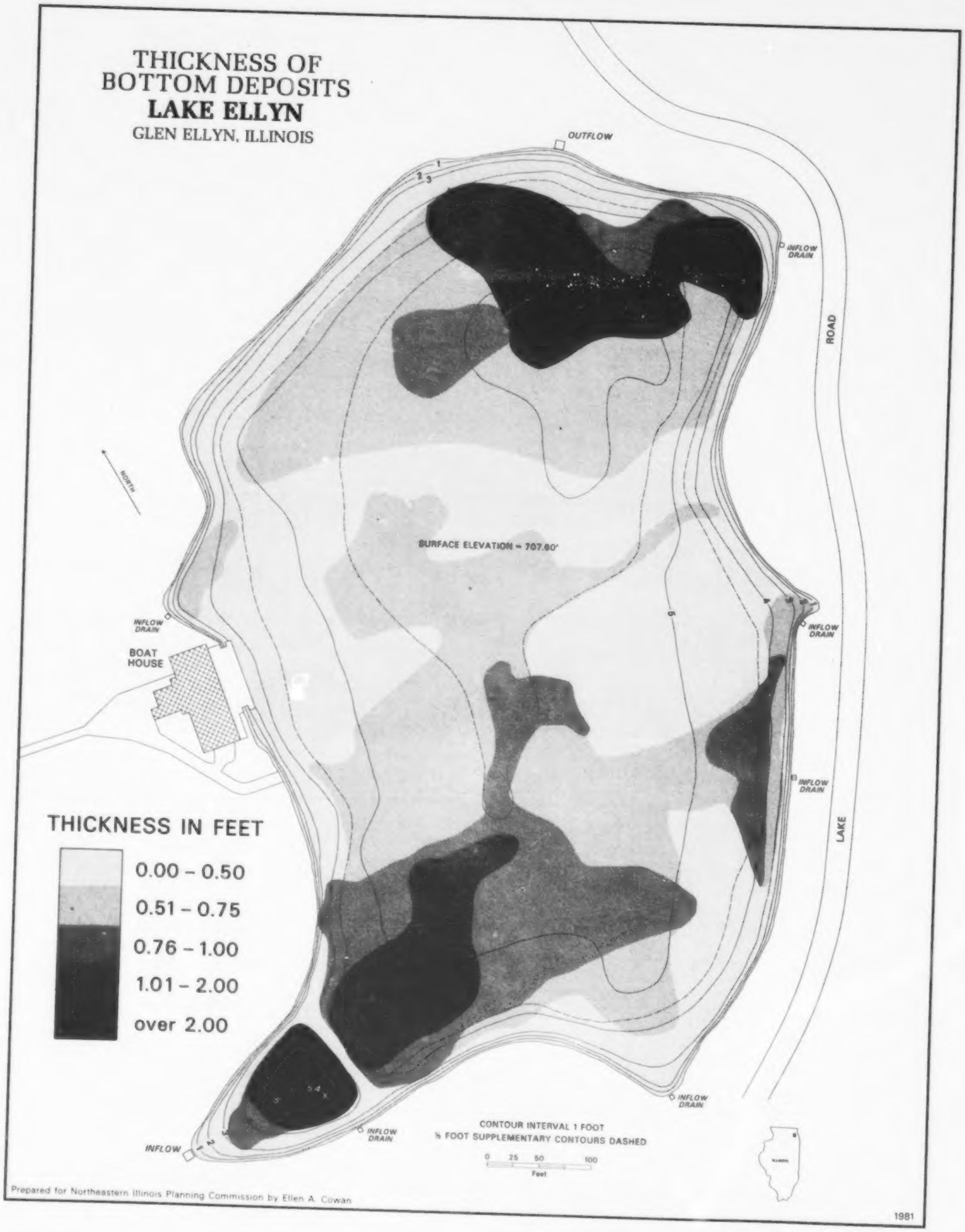
Stormwater is the most important source of phosphorus (52 percent), copper (85 percent), lead (95 percent), and zinc (62 percent). Baseflow contributes most of the chloride (95,400 pounds annually or 70 percent of total load) and 40 percent of the phoshorus load. Roof runoff is responsible for 28 percent (50.5 pounds annually) of the zinc loads.

Chloride levels in Lake Ellyn are highest in early spring (170 ppm) and lowest in late fall (39 ppm). High concentrations correspond to the time when salt is being applied to streets and washed into the lake. Phosphate, ammonia, and metal concentrations in the lake are highest in the summer. These high concentrations result from stormwater runoff, most of which occurs in late spring and summer.

The concentration and load reductions are, of course, gained by an increase in constituents in the sediments. Figure 4 shows the distribution of sediments. Figure 4 shows the distribution of sedient in Lake Ellyn. Almost 87 percent of the sediment in Lake Ellyn is less than 63 microns in diameter (Figure 3). In regard to organic matter, nutrients and heavy metals, the sediments found in Lake Ellyn are well above ranges found in normal, non-urban lakes. Lead and phosphorus are extreme cases. The range of lead concentrations in a rural lake might be from 15 to 100 ppm while the concentrations found in Lake Ellyn sediments is over 1,000 ppm. The higher content of organic material causes depressed oxygen concentrations at and near the solid/aqueous interface which not only affects aquatic life in this zone but also chemical transformations such as the reduction of nitrates and dissolution of lead and other heavy metals.

Although some priority pollutants were found in Lake Ellyn sediment (e.g. a phthalate ester and numerous polycyclic aromatic hydrocarbons), none were present in sufficient concentrations for concern. Lake Ellyn sediment does not qualify as a hazardous waste under USEPA's EP toxicity criteria.

There are four physical features of Lake Ellyn which make possible the high trap efficiencies and, thereby the modification of urban stormwater constituent concentrations. The first of these features is that the inlet is separated from the outlet by approximately 600 feet, at the opposite end of the lake. The second is the existence of a submerged dam, near the inlet, which dissipates and distributes the energy of incoming stormwater, it all but eliminates the possiblity of short circuiting (see Figure 4). The third is that the lake volume of detained water (45.0 acre feet) is sufficient to ensure that there is only a small chance that a runoff event will totally displace the resident water volume. Settling column tests on influent stormwater to Lake Ellyn indicated that 95 percent of suspended material would settle in four hours (Figure 5). Consequently, the effluent, under most hydrologic conditions, is simply displaced lake water and not the immediate runoff from the watershed. Fourth, the mean depth of the lake is five feet which is deep enough to ensure that the zone of consolidation is undistrubed by the movement of water through the lake; consequently,



THICKNESS OF
BOTTOM DEPOSITS
LAKE ELLYN
GLEN ELLYN, ILLINOIS
OUTFLOW
INFLOW DRAIN
ROAD
LAKE
NORTH
SURFACE ELEVATION = 707.60'
INFLOW DRAIN
BOAT HOUSE
INFLOW DRAIN
INFLOW DRAIN
THICKNESS IN FEET
0.00 – 0.50
0.51 – 0.75
0.76 – 1.00
1.01 – 2.00
over 2.00
INFLOW DRAIN
INFLOW DRAIN
INFLOW
CONTOUR INTERVAL 1 FOOT
½ FOOT SUPPLEMENTARY CONTOURS DASHED
0 25 50 100
Feet
ILLINOIS
Prepared for Northeastern Illinois Planning Commission by Ellen A. Cowan
1981

Figure 4. Thickness of Bottom Deposits Lake Ellyn, Glen Ellyn, Illinois

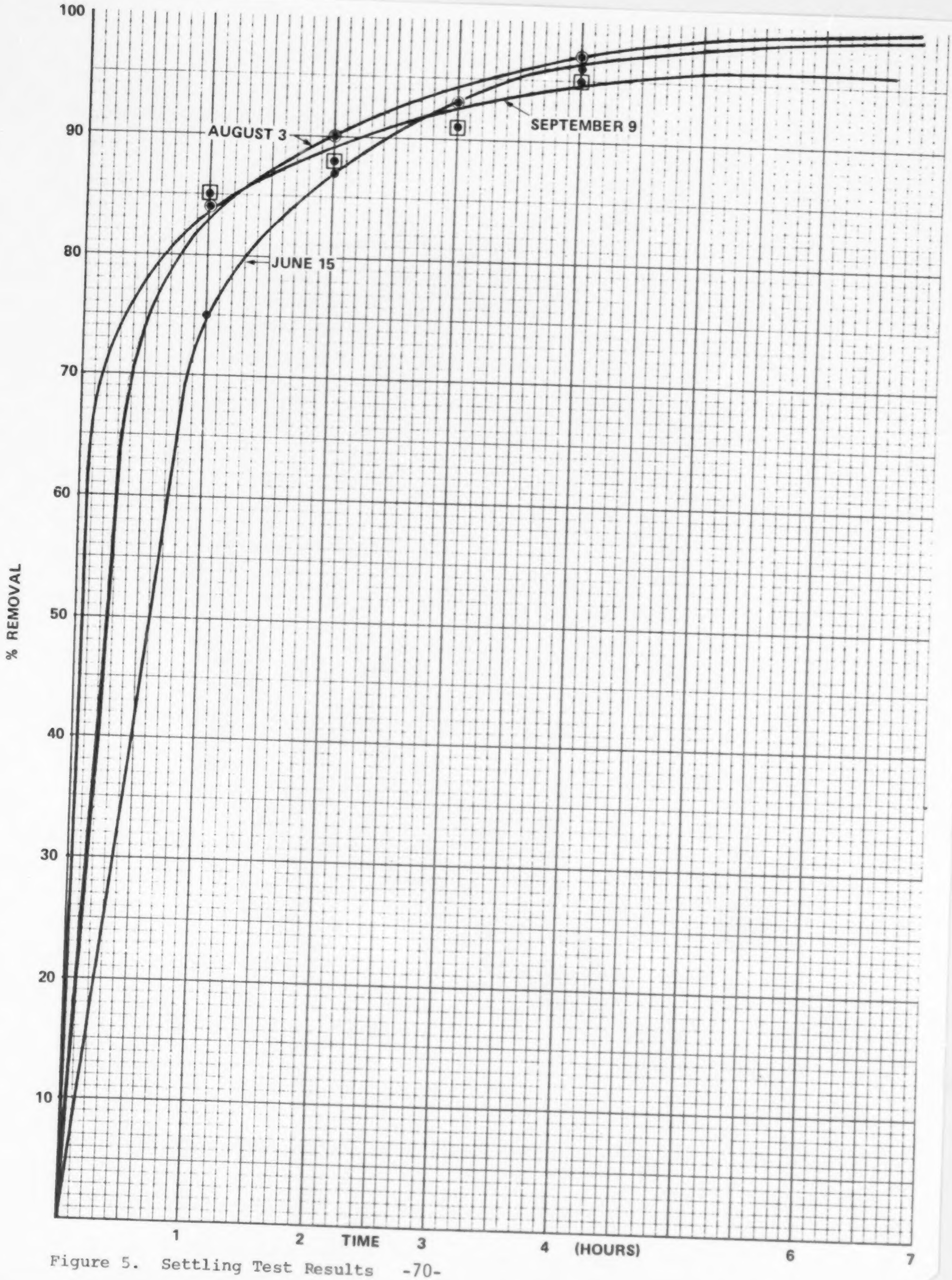


Figure 5. Settling Test Results

materials that settle are not subsequently entrained. The only materials that re-enter the water column, at least in regard to the measurements taken during this study, were those constituents that were dissolved by one means or another after entering the lake.

Source Control

Source control is not a practical means for reducing urban stormwater constituents in the Lake Ellyn watershed. The sources of contaminants are very diverse, and in many instances, the principal source is an essential component of society (automobiles), a service demanded by the public (street salting) or a source already being controlled to the maximum extent practical (soil erosion). For example, none of the four principal sources of total solids (soils, street salting, pavement decomposition, and vegetation) are responsible alone for more than one-third of the total solids load. Glen Ellyn's streets are all in generally good condition and the watershed is well turfed making further control of solids from these sources impractical. Glen Ellyn also collects grass clippings and fallen leaves on a routine basis so that improvement in controlling this source is also not practical. Discontinuing street salting would virtually eliminate chloride loads but this action would cause winter driving hazards.

Phosphorus loads result from vegetation, animals, and fertilizer applications. Control of wild animals is obviously impractical and no adequate substitute is available for fertilizer applications, given social attitudes about urban landscapes.

Most of the copper and lead come from traffic. Elimination of this source from the Lake Ellyn watershed is obviously feasible. No single source of zinc contributes more than 30 percent of total zinc. Important sources are the decomposition of building materials, traffic, atmospheric deposition and vegetation. Replacement of galvanized building materials is an expensive proposition and would only eliminate 29 percent of zinc loads. Reduction of atmospheric load would require regional control strategies but would only eliminate 23 percent of zinc loads to the transport system.

RECOMMMENDATIONS

Source Control

At a minimum, a basic program of source control should be carried out by management agencies responsible for urban watersheds. Such programs, found to be important in the Lake Ellyn watershed, should encompass erosion control, collection of leaves and grass clippings, minimal application of road salt for ice control and routine street surface maintenance. If a sound source control program is already in place in an urban watershed, further investments are not recommended since, based on study results, they will have little effect on receiving water pollutant loads.

Special efforts should be directed at toxic materials. Source control is the only effective means for keeping these substances out of receiving waters. Urban management agencies must question the benefits of using materials containing toxic substances versus the risk posed by their release to the environment. Where it is essential that toxic materials be used, application programs should be carefully designed to prevent the introduction of these substances to transport systems (e.g. observing recommended application rates and conditions, avoiding overspray to streets and sewers, considering climatic factors such as likelihood of precipitation).

Street Sweeping

Street sweeping should not be employed beyond levels of "good housekeeping" since this is an ineffective means of removing pollutants in street materials in this climatic region. Street sweeping should continue to be used for general street litter control to yield aesthetic benefits.

Catch Basins

Catch basins should not be considered an effective means of controlling urban stormwater pollutants. Further investment in catch basins for stormwater pollution control is not recommended.

Detention Storage

Wet-bottom detention storage should be employed where water resources benefits can be obtained through reductions of urban stormwater pollutants.

Detention facilities should be designed to serve regional rather than on-site needs in order to maximize pollutant removal capabilities and secure additional benefits such as aesthetics and aquatic life, and recreation. The design of detention facilities should consider the following criteria with respect to volume, depth, and inlet/outlet relationships.

To ensure high trap efficiency and corresponding reduction in constituent concentrations, inlets and outlets of detention facilities should be separated to the maximum extent possible. Detention facilities also need to be sufficiently deep to preclude entrainment of trapped materials from the zone of consolidation. Depth should also be sufficient to provide for maintenance of fish life, but not so deep that they promote anoxic conditions leading to nuisances (e.g. odors) and chemical transformations which adversely affect the quality of the effluent. Typically, critical depths to avoid anoxic conditions are a function of reaeration potential and vary from lake to lake. In general, depths over ten feet may present the possibility of stratification and anoxic conditions unless mechanical aeration is provided.

To promote the use of detention facilities, the design should accommodate public access and reflect community values. In this regard, bank slopes should be very gradual ensuring easy access to the water without the fear of slipping or falling. The banks should be protected from erosion by vegetative cover or by other suitable materials. Aquatic habitats, including the placement of appropriate substrate materials and plants, should be provided if the propagation of fish and species diversity is desired. Finally, access for maintenance equipment should be incorporated into the design.

EFFECTS OF AN URBAN LAKE ON STORMWATER RUNOFF AND QUALITY

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INTRODUCTION

Runoff from urban watersheds has been identified as an important source of constituent loading to streams and rivers [1,2]. Consequently, recent studies in urban hydrology have focused on evaluation of various resource management practices which are intended to improve the quality of urban runoff. One strategy is detention storage, the practice of routing runoff through a lake or pond prior to release to a receiving stream.

The purpose of this article is to discuss the effects that detention storage were observed to have on urban runoff at a small lake in northeastern Illinois. In an effort to evaluate these effects, the U.S. Geological Survey in cooperation with Northeastern Illinois Planning Commission (NIPC) observed inflow and outflow quantity and quality at Lake Ellyn, located in the western Chicago suburb of Glen Ellyn, Illinois. From February 1980 through September 1981, the flow information was collected continuously at the principal inlet and at the outlets of Lake Ellyn. Water-quality samples were collected throughout rainfall-runoff and snowmelt-runoff periods so that chemical and sediment loads could be calculated. Inflow and outflow loads were compared to determine the effects of Lake Ellyn in altering the quality of the runoff.

ACKNOWLEDGMENTS

Funds for the Lake Ellyn study were provided by the U.S. Environmental Protection Agency as part of the Nationwide Urban Runoff Program and by the Illinois Department of Energy and Natural Resources through NIPC. The village of Glen Ellyn, the Glen Ellyn Park District, and Glenbard West High School provided the study area and project assistance.

STUDY AREA

Lake Ellyn is a 10.2-acre impoundment which receives drainage from a 534-acre, urban watershed (figure 1). Physiographic and land use characteristics of the watershed as determined by NIPC [3] are listed in table 1. Surface inflows from 95 percent of the watershed is park land which drains overland into the lake. The main storm drain (Main Inlet) conveys runoff from 70 percent of the watershed. Lake outflows are controlled by two weirs on the opposite side of the lake from Main Inlet.

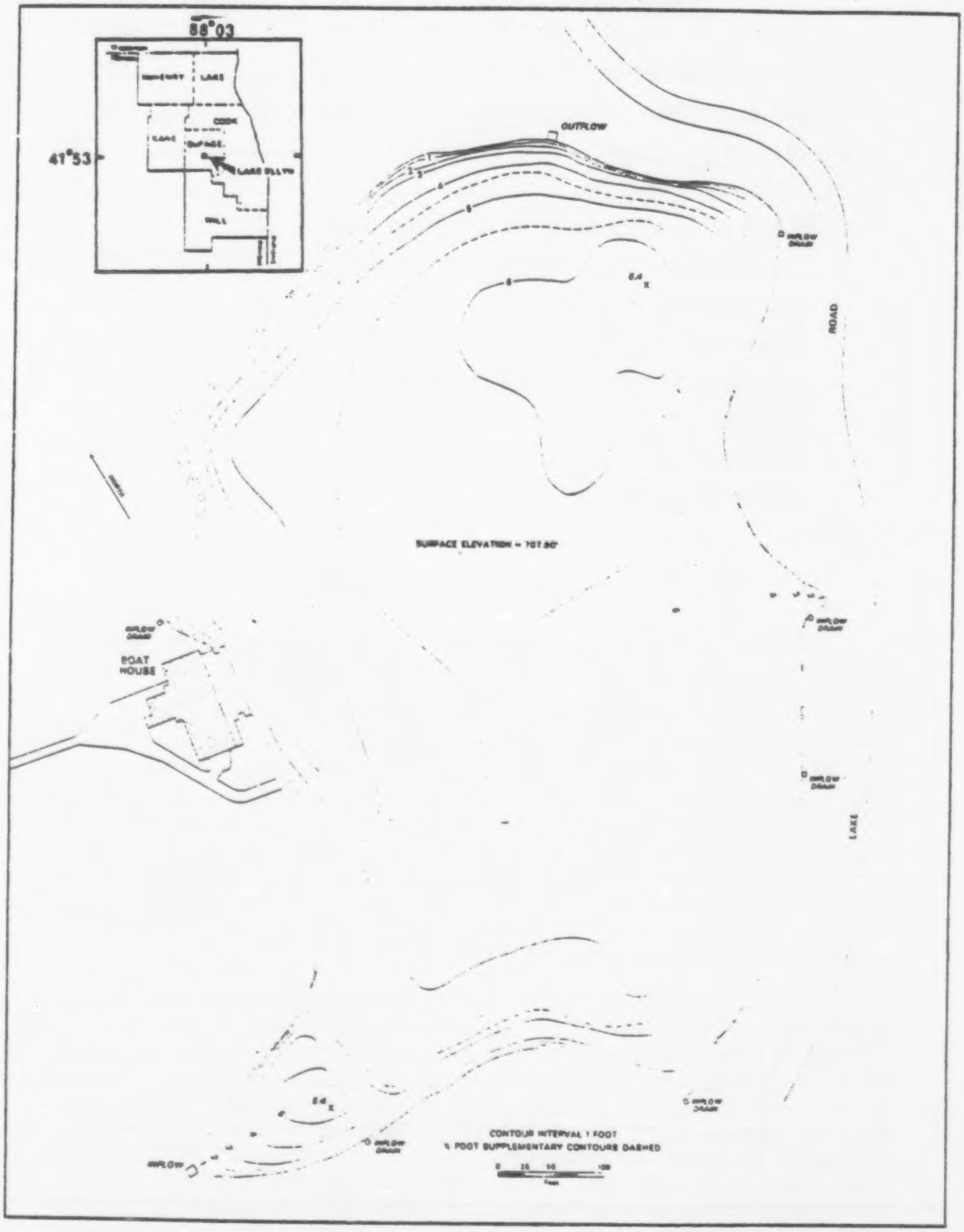
88°03
41°53
MCHENRY
LAKE
COOK
KANE
DUPAGE
LAKE ELLYN
WILL
OUTFLOW
INFLOW DRAIN
ROAD
LAKE
BOAT HOUSE
INFLOW
SURFACE ELEVATION = 707.80'
CONTOUR INTERVAL 1 FOOT
½ FOOT SUPPLEMENTARY CONTOURS DASHED
0 25 50 100
Feet

Figure 1. Depth contours for Lake Ellyn at Glen Ellyn, IL. (Modified from Hey and Schaefer, 1983.)

Table 1. Physiographic and land use characteristics of the Lake Ellyn watershed.

[Modified from Hey and Schaefer, 1983.]

Total drainage area, in acres	534
Impervious area, in percentage of drainage area	34
Average basin slope, in percent	4.2
Detention storage, in acre feet	44.8
Lake use as a percentage of drainage area:	
Low density single family residential	80
High density residential	3
Commercial	5
Under construction (bare surface)	0
Wetland	2
Parkland	5
Institutional	5

DISCUSSION AND RESULTS

Changes in runoff quality which may be attributed to detention storage are observed as differences in concentrations and mass loads between inflow and outflow. Chemical and sediment concentrations in inflow to Lake Ellyn are highly variable depending upon discharge, local constituent sources, season, antecedent conditions, and rainfall intensity. Lake outflow varies less in chemical and sediment concentration than runoff (figure 2). Although less variable, mean concentrations in outflow may be either greater or less than inflow concentrations. Suspended solids and metals, such as lead, which can sorb to sediment particle surfaces, are in consistently lower concentrations in outflow, than in inflow, whereas dissolved constituent concentrations are often higher. Figure 3 illustrates the annual cycle of dissolved solids, chloride and calcium concentrations observed in outflow.

Peaks in dissolved solids and chloride concentrations are largely attributed to deicing salt. The corresponding peak in calcium concentration may be attributed to the deicing salts or to the increased lake water residence time during winter which may be sufficient for exchange or solution reactions. The minimum concentrations of dissolved constituents in outflow occur in early fall. Concentrations of dissolved constituents in low-flow samples collected at Main Inlet at that time, are lower than at the outlet. This condition and the cyclical nature of the hydrograph in figure 3 suggests that Lake Ellyn is annually flushing road salts and other dissolved ions which are carried to the lake during the winter. Concentrations above those in low flow would have indicated a

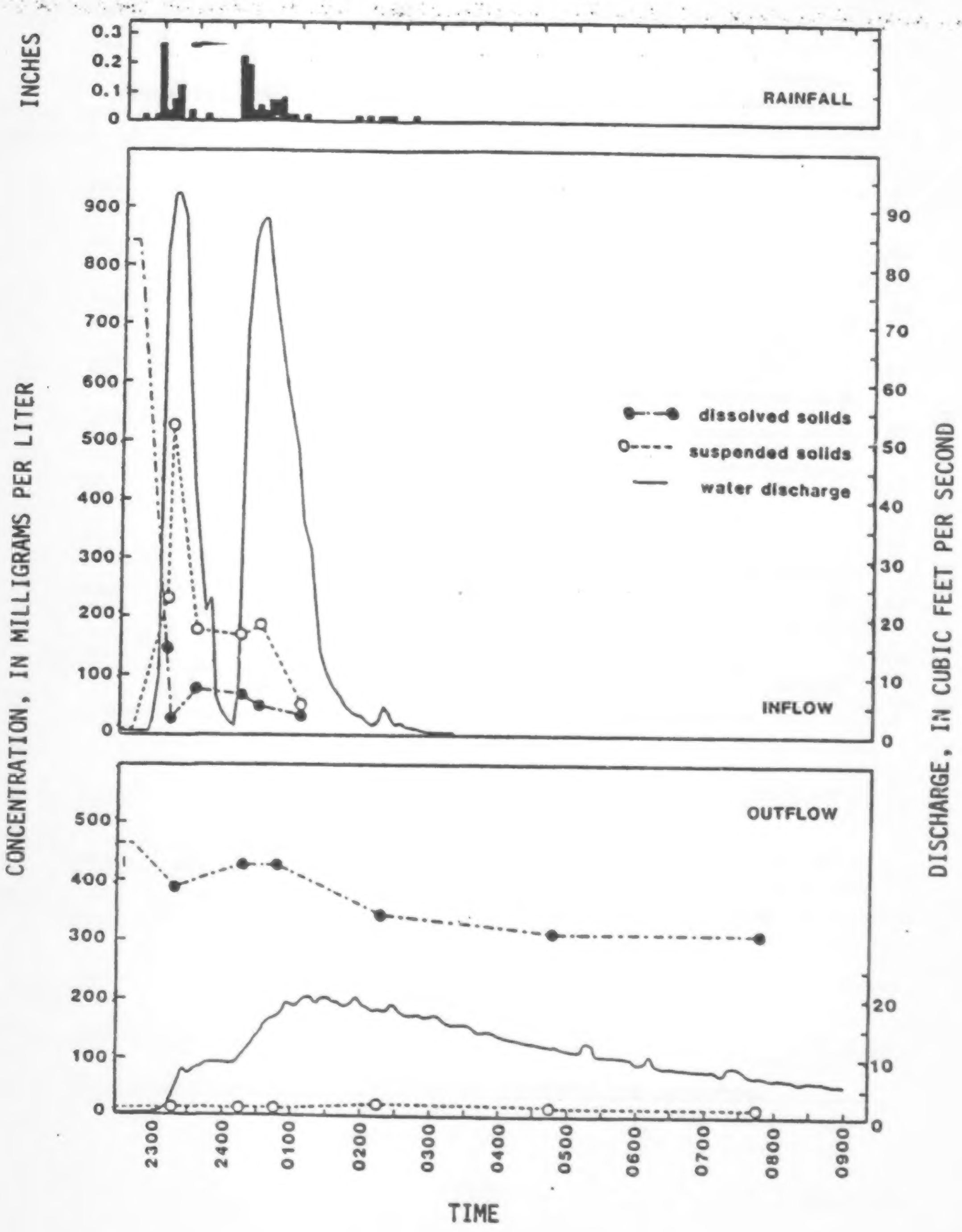

Figure 2. Water discharge, dissolved solids, and suspended solids hydrographs for Lake Ellyn at Glen Ellyn, Illinois, July 20-21, 1980.

potential for the buildup of dissolved constituents in the lake. Such buildups have been observed to cause temporary or permanent chemical stratification (meromixis) in other lakes in urban areas [4,5].

Inflow to outflow chemical and sediment mass balances must be evaluated by examining the volume and concentrations of all water entering and leaving a lake. A general water balance for a lake is defined by

$$Q_{ig} + Q_{iu} + G_i + P = Q_{og} + G_o + E \qquad (1)$$

where

Q = surface-water discharge,
G = ground-water discharge,
P = precipitation on lake surface,
E = evaporation from lake surface,

i = inflow,
o = outflow,
g = gaged, and
u = ungaged.

Ground water-surface water interchange was assumed to be negligible at Lake Ellyn because the deepest point in the lake is approximately 10 feet above the water table, the lake is clay lined, and it overlies glacial lacustrine sediments. Runoff duration is relatively short, so evaporation was ignored. All surface water outflow was gaged. The water balance equation for Lake Ellyn therefore reduces to:

$$Q_o = Q_{ig} + Q_{iu} + P \qquad (2)$$

and all variables were measured except Q_{iu}.

The primary interest in inflow-to-outflow mass balances at Lake Ellyn was to determine the efficiency of the lake in retaining constituents transported by runoff. Retention efficiencies for any constituent for any time period can be calculated by:

$$R = (1 - \frac{L_o}{L_i}) \times 100 \qquad (3)$$

where

R = retention efficiency, in percent,
L_o = mass of any constituent in outflow, and
L_i = mass of any constituent in inflow.

For Lake Ellyn:

$$L_o = (Q_{og}) (\overline{C}_o) \qquad (4)$$

where

Q_{og} = gaged outflow discharge for a period of time, and
$\overline{C}_o$ = mean concentration of a constituent in outflow for the same time period.

The total outflow load was measured at Lake Ellyn. Calculation of a mass balance requires that some components of the mass input to the lake (L_i) be estimated:

$$L_i = (Q_{ig})\ (\overline{C}_{im}) + (Q_{iu})\ (C_{iue}) + (P)\ (C_{pe}) \qquad (5)$$

where "m" represents measured concentrations, "e" represents estimated concentrations, and other symbols are identified with equations 1 and 3. Of the six variables, two are estimated, and Q_{ui} is calculated as a residual of Q_{ig} and P. Retention efficiencies calculated by substituting equations 4 and 5 into equation 3 may have a large error due to estimation of some parameters.

Because of the uncertainties in the individually calculated values of retention efficiency, a range of retention efficiencies was calculated within which the actual R for Lake Ellyn should lie. The gaged Main Inlet which drains downtown Glen Ellyn is assumed to have higher constituent concentrations than the ungaged inflow. A minimum retention efficiency could be calculated by ignoring the ungaged inflow. In this case, R_{min} is calculated by:

$$R_{min} = 1 - \frac{(Q_o)\ (\overline{C}_{om})}{(Q_{ig})\ (\overline{C}_{im})} \times 100 \qquad (6)$$

A maximum retention efficiency could be calculated by assuming that the volume of inflow is equal to the volume of outflow and that the concentration in all the inflow is the same as the high concentrations measured at Main Inlet. In this case, R_{max} is calculated by:

$$R_{max} = 1 - \frac{(Q_o)\ (\overline{C}_{om})}{(Q_o)\ (\overline{C}_{im})} \times 100$$

which simplifies to:

$$R_{max} = 1 - \frac{\overline{C}_{om}}{\overline{C}_{im}} \times 100. \qquad (7)$$

Equations 6 and 7 are simple models for estimating retention efficiencies for Lake Ellyn. They are reliable, when adequate data are available, for relatively nonreactive constituents transported during high-flow periods. Calculating retention efficiencies for constituents that have multiple sources and sinks, or that are highly reactive, would require expansion of equations 6 and 7.

Table 2 presents mass balances and calculated ranges of retention efficiencies for suspended solids and metals. The constituent data are averages for 17 rainfall-runoff periods during 1980-81. Lake Ellyn is highly efficient in the removal of suspended concentrations of solids, lead, copper, and zinc from runoff. Similar retention efficiencies would be expected for other metals transported in association with suspended solids.

Table 2. Retention efficiencies of Lake Ellyn for suspended solids and selected metals averaged for 17 rainfall-runoff periods in 1980-81.

Constituent	A Measured inflow load, in kilograms $(Q_{ig})\ (\overline{C}_{im})$	B Calculated maximum inflow load, in kilograms $(Q_o)\ (\overline{C}_{im})$	C Measured outflow load, in kilograms $(Q_o)\ (\overline{C}_{om})$	C/A Minimum retention efficiency, in percent	C/B Maximum retention efficiency, in percent
Suspended solids	38,000	77,000	4,600	88	94
Suspended lead	38	75	3.3	91	96
Suspended copper	4.9	9.8	0.4	92	96
Suspended zinc	23	44	4.9	79	89

Average retention efficiencies, calculated from average concentrations of selected dissolved constituents during storm runoff periods, are negative (table 3) indicating that dissolved constituents do not immediately flush through the lake. The hydrograph shown in figure 3, however, shows that there is no buildup in dissolved concentrations. More intensive sampling during low-flow periods would be required to obtain reliable retention efficiencies for dissolved constituents.

Table 3. Retention efficiencies of Lake Ellyn for major ions and dissolved metals averaged for 17 rainfall-runoff periods in 1980-81.

Constituent	A Measured inflow load, in kilograms $(Q_{ig})\ (\overline{C}_{im})$	B Calculated maximum inflow load, in kilograms $(Q_o)\ (\overline{C}_{im})$	C Measured outflow load, in kilograms $(Q_o)\ (\overline{C}_{om})$	C/A Minimum retention efficiency, in percent	C/B Maximum retention efficiency, in percent
Chloride	5,500	11,000	36,000	-550	-230
Sodium	4,500	9,000	16,000	-260	-78
Calcium	2,500	4,800	9,600	-280	-100
Magnesium	1,000	2,000	5,400	-440	-170
Sulfate (S)	3,500	7,000	11,000	-210	-57
Copper, dissolved	0.8	1.6	0.9	-12	44
Lead, dissolved	0.5	1.0	4.4	-780	-340
Zinc, dissolved	3.8	7.7	1.5	61	81

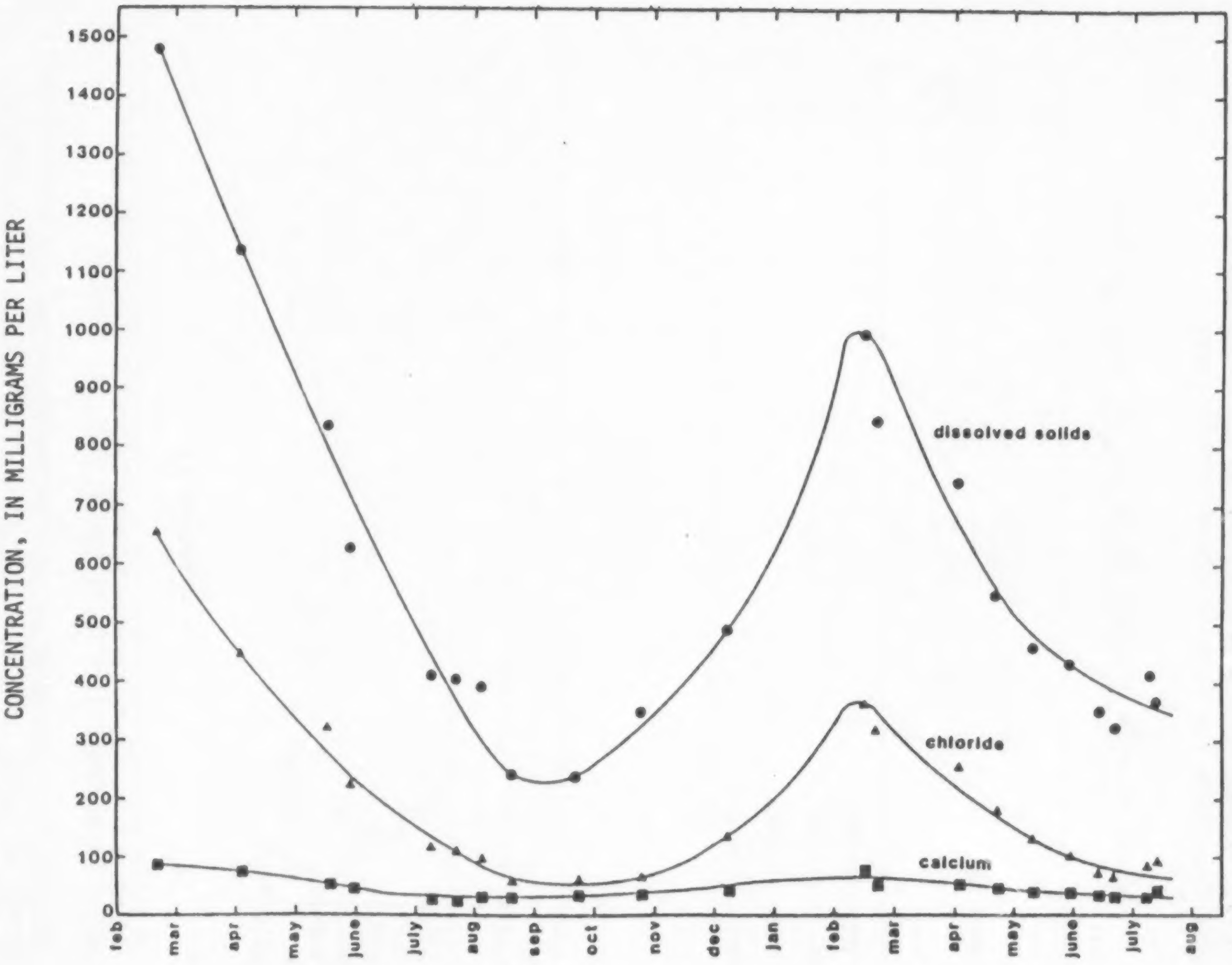

Figure 3. Dissolved solids, chloride, and calcium concentrations in flow to Lake Ellyn at Glen Ellyn, Illinois, 1980-81.

Retention efficiencies of suspended and dissolved nitrogen and phosphorus are listed in table 4. In general, retention efficiencies for suspended nutrients are less than those for other suspended constituents, whereas retention efficiencies for dissolved nutrients are greater than those for other dissolved constituents.

Table 4. Retention efficiencies of Lake Ellyn for nitrogen and phosphorus averaged for 17 rainfall-runoff periods in 1980-81.

Constituent	A Measured inflow load, in kilograms $(Q_{ig})\ (\bar{C}_{im})$	B Calculated maximum inflow load, in kilograms $(Q_o)\ (\bar{C}_{im})$	C Measured outflow load, in kilograms $(Q_o)\ (\bar{C}_{om})$	C/A Minimum retention efficiency, in percent	C/B Maximum retention efficiency, in percent
Nitrogen, suspended	210	440	210	0	51
Nitrogen, dissolved	150	290	140	7	52
Phosphorus, suspended	45	91	32	29	65
Phosphorus, dissolved	8.0	15	8.8	-10	61

CONCLUSIONS

Detention storage in Lake Ellyn results in high retention efficiencies for solids and sediment-associated metals in runoff. Chloride concentration in inflow are high during winter due to deicing salt and there are large seasonal variations in concentrations of many dissolved constituents in outflow. Sampling of lake inflow for chloride and other dissolved constituents provided insufficient data with which to calculate reliable retention efficiencies. However, concentration hydrographs of dissolved constituents indicate there is no retention from year to year. Retention efficiencies for suspended nitrogen and phosphorus are less than those for other suspended constituents and those for dissolved nitrogen and phosphorus are greater than those for other dissolved constituents.

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EFFECTS OF URBANIZATION ON RECEIVING WATERS

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INTRODUCTION

The most important element in an urban runoff study is defining and recognizing an urban runoff problem. It is not very effective to implement a control program that does not reflect the specific problems and the measured, or assumed, cause and effect relationships. The easiest way to identify problems is to examine the established and accepted beneficial uses of the receiving water. If these uses are degraded, then cause and effect relationships need to be investigated. This difficult and sometimes not determinable task then leads to the rationale for the control program.

Well documented cases of receiving water detrimental effects caused by urban runoff are rare. Several studies have identified poor water quality conditions in urban receiving waters, but implied cause and effect relationships are difficult to confirm. This paper summarizes some urban runoff studies conducted before 1980 that investigated urban runoff problems, mostly based on reviewing data that had been previously obtained. Two recent West Coast studies that specifically investigated urban runoff effects through major field programs are also summarized.

PRIOR STUDIES

Heaney, et al [1] evaluated the existing literature pertaining to urban runoff effects on receiving waters. They found that well documented cases of receiving water detrimental effects were scarce. Through their review of many reports, they found several reasons to question the implied cause and effect relationships between urban runoff and receiving water conditions. Impacts that were attributed to urban runoff were probably caused, in many cases, by other water pollution sources (such as combined sewer overflows, agricultural nonpoint sources, etc.). One of the major difficulties encountered in their study was the definition of "problem" that had been used in the reviewed projects. They found that very little substantive data had been collected to document beneficial use impairments. In addition, urban runoff impacts are most likely to be associated with small receiving waters, while most of the existing urban water quality monitoring information exists for larger bodies of water. It was also very difficult for many researchers to isolate urban runoff effects from other water pollutant sources, such as municipal and industrial wastes. This was especially important in areas that had combined sewers that overflowed during wet weather contributing to the receiving water impacts during wet weather conditions.

Heaney, et al [1] also reviewed fish kill information reported to government agencies during 1970 to 1979. They found that less than three percent of the reported 10,000 fish kills were identified as having been caused by urban runoff. This is less than 300 fish kills nationwide for ten years. A substantial number of these 10,000 fish kills were not identified as having any direct cause. It is expected that many of these fish kills could have been caused by urban runoff, or a combination of problems that could have been worsened by urban runoff. Their review of studies that examined dissolved oxygen (DO) values obtained downstream from urbanized areas indicated that the worst dissolved oxygen levels occurred after storms in about one-third of the cases studied. This lowered DO could be due to urban runoff moving downstream, combined sewer overflows and/or resuspension of benthic deposits. Resuspended benthic deposits could have been previously settled urban runoff settleable solids. They also reported a study conducted by the National Water Quality Inventory Series that indicated that 12 out of 26 water quality constituents studied had higher concentrations during high flow periods.

Heaney, et al [1] found, in their review of past studies, that worst case conditions do not always occur during the low flow periods following storms. The most studied urban runoff effect has been dissolved oxygen in the receiving waters. Because of the relatively high immediate oxygen demand of urban runoff a substantial oxygen consumption may occur during high flow periods [2]. However, these high flow periods also have high reaeration conditions and dissolved oxygen depletion during runoff events is very site dependent. Pitt [2] found that the biochemical oxygen demand of urban runoff after a 10 to 20 day incubation period can be more than five to ten times the biochemical oxygen demand of a one to five day incubation period. Therefore, urban runoff effects on dissolved oxygen may occur at times substantially different from the actual storm period. In addition, sediment accumulation associated with urban runoff solids is expected to create the most severe long term effect of urban runoff, especially for heavy metals.

Urban Runoff Receiving Water Types

As part of their comprehensive study of urban runoff effects, Heaney, et al [1] summarized typical urban receiving water types. About 85 percent of the primary receiving waters adjacent to urbanized areas are rivers. Most of these have flows of less than 300 cubic meters per second (10,000 CFS), and about 20 percent of the total receiving waters have flows of less than three cubic meters per second (100 CFS). Lakes make up about five percent of the total urban area receiving waters, with large lakes being more common than small lakes. Estuaries and oceans make up about ten percent of the total urban receiving waters and about half of these are open oceans or beaches. The rest are estuaries having depths of between three and ten meters (10 and 30 feet).

Those receiving waters that are likely to have the most prominent effects associated with urban runoff include small ponds and backwaters (about 0.5 percent of all the urban receiving waters), small creeks and shallow streams (about 20 percent of all the urbanized receiving waters), and shallow estuaries or bays less than three meters deep (about 0.5 percent of all urban receiving waters). The small ponds and backwaters are likely to experience the worst receiving water effects because of their limited dilution capabilities and circulation patterns.

This distribution of receiving waters, however, may be misleading. As an example, according to Heaney et al. [1], large rivers were considered to be the receiving waters for many urban areas, while actually small creeks and streams are the major conveyance routes for urban runoff to these larger rivers. These small creeks would experience a much more pronounced effect. Therefore, receiving water types most likely to experience receiving water problems are most likely greater than the 20 percent noted above.

Urban Runoff Effects on Receiving Water Dissolved Oxygen

The most comprehensive studies examined long term records of dissolved oxygen on a national or regional basis. Keefer et al. [3] examined the data from 104 water quality monitoring sites near urban areas throughout the country for dissolved oxygen conditions. These stations were selected from more than 1,000 nationwide monitoring stations operated by various federal and state agencies. They conducted analyses of daily dissolved oxygen data for 83 of these sites. About one-half of the monitoring stations examined showed a 60 percent or greater, probability of a higher than average dissolved oxygen deficit occurring at times of higher than average streamflow, or on days with rainfall. This result was based upon daily data for entire water years; not all years at any given location exhibited this 60 percent probability condition. They found that the DO levels fell to less than 75 percent saturation at most of the stations that had this 60 percent or greater probability condition. They also found that DO concentrations of less than 5 mg/l were common.

Another study that examined dissolved oxygen depletion on a regional basis was conducted by Ketchum [4]. This study examined dissolved oxygen data in Indiana. Sampling was conducted at nine cities and the project was designed to detect significant dissolved oxygen deficits in streams during periods of rainfall and runoff. The results of this study indicated that wet weather DO levels generally appear to be similar or higher than those observed during dry weather conditions in the same streams. They found that significant wet weather DO depletions were not observed, and due to the screening nature of the sampling program, more subtle impacts could not be measured. As noted previously, adverse dissolved oxygen conditions associated with urban runoff are likely to occur a substantial time after the runoff event and downstream from the discharge locations.

Sediment Quality Effects

Wilber and Hunter [5], in their studies on the Saddle River near Lodi, New Jersey, found that the location of the sampling station in the receiving water was the most important element in determining heavy metal concentrations in the sediments for all constituents, except for common iron and manganese. Iron and manganese are present in very high concentrations in rocks, minerals and soils and urbanization contributes very little additional iron and manganese to the system. Wilber and Hunter [5] found significant enrichments of several heavy metals in the sediments of the lower Saddle River that was affected by urbanization, as compared to the more rural upper Saddle River. The increases in heavy metal sediment concentrations from the stream above the urban area to the area below the urban center of Lodi, were 6.7 for lead, 3.5 for zinc, 3.1 for copper, 2.8 for nickel, 5.1 for chromium, 5.2 for cadmium, 1.2 for manganese and 1.8 for iron. The concentration of available (readily soluble) lead, zinc, copper and nickel in bottom sediments also increased from the upstream nonurban to the urban sections of the Saddle River. These available heavy metal sediment concentration increases were 3.2 for lead, 6.1 for zinc, 4.2 for copper and 4.3 for nickel.

Rolfe and Reinbold [6], in their study near Champaign-Urbana, Illinois, found that lead concentrations in the top ten centimeters of stream sediments were much higher in the urban stream reach (almost 400 ug/l) than in rural streams in the same area. They also found a greater diversity of plants and animals in the rural streams than in the urban streams.

Wilber and Hunter [5] also found that the metal concentrations in the sediments was strongly dependent upon particle size. Generally, metal concentrations increased with decreasing particle size. This is a typical conclusion for most urban runoff solids. It appears that most of the urban runoff heavy metals are associated with very fine particles. Unnaturally high concentrations of heavy metals can be associated with larger particle sizes, but these concentration increases are expected to occur through the adsorption of the smaller, more polluted, particles onto the larger particles. They found that the largest size fractions studied showed greater metal enrichments than the smaller sediment fractions between the nonurbanized and the downstream urbanized area. They felt that because the larger sediment fractions are least affected by scour and transport, they may best reflect the impact of urbanization and the distribution of heavy metals over an extended period of time at any given location. This assumes that the smaller particle sizes are transported through the system after rain events much more rapidly than the larger particle sizes. They found that the greatest total quantity of heavy metals occurred, by far, in the size fraction greater than 125 microns, because there was so much more of the larger material in the sediments.

Effects of Urban Runoff on Aquatic Organisms

Kuehne [7] studied the recoverability of a small urban stream by examining the repopulation of aquatic organisms after major improvements in a wastewater treatment facility were made. He found that the diversity of benthic macroinvertebrates increased at most of the locations formerly affected by pollution, but did not achieve the same population conditions as at two control sections on a creek that were never adversely affected. He found that fish recolonized the previously impacted creek more rapidly than invertebrates, but they also did not achieve the diversity observed at the control section, or that had been observed 15 years before the water pollution occurred. He felt that urbanization in the area may be causing physical, chemical and biological changes further affecting the creek besides the wastewater effluent pollution. This study did show that improving the quality of an urban creek can substantially improve the biological and aesthetic conditions. However, the presence of uncontaminated tributaries was thought to have sped the observed recovery.

COYOTE CREEK STUDY

The Coyote Creek study was conducted by Pitt and Bozeman [8], with funding from the Storm and Combined Sewer Section of the U.S. Environmental Protection Agency. The objective of this three-year monitoring study was to evaluate the sources and impacts of urban runoff on water quality and biological conditions in Coyote Creek. The three major elements of this study included: (1) identifying and describing important sources of urban runoff pollutants, (2) describing the effects of those pollutants on water quality, sediment quality, aquatic organisms, and the creeks' associated beneficial uses, and (3) assessing potential measures for controlling the problem pollutants in urban runoff. In many cases, very pronounced gradients of water and biological quality indicators were observed. Cause-and-effect relationships cannot be conclusively proven in a study such as this, the degradation of conditions in Coyote Creek may be due to several factors, including urban runoff, stream flows (both associated and not associated with urban runoff), and natural conditions (e.g., drought, stream gradient, groundwater infiltration, etc.). Information collected during this study implied that the effects of various urban runoff constituents, especially organics and heavy metals in the water and in the polluted sediment, may be responsible for much of the adverse biological conditions observed.

Site Description

Coyote Creek flows through San Jose, California, as a small stream, just a few meters in width, but it is about 130 kilometers (80 miles) long and drains an area of about 80,000 ha (200,000 acres). It originates in a wilderness area that is virtually free of pollutant sources.

During the field program, 41 stations were sampled in both urban and nonurban perennial flow stretches of the creek. Short and long-term sampling techniques were used to evaluate the effects of urban runoff on water quality, sediment properties, fish, macroinvertebrates, attached algae, and rooted aquatic vegetation. The program was designed to define receiving water conditions in the urban and nonurban areas during dry weather conditions.

Coyote Creek Water Quality

The purpose of the water quality monitoring program on Coyote Creek was to define receiving water conditions in the urban and nonurban areas during dry weather. Dry weather conditions were studied because they reflect long-term water quality characteristics in the creek and are less influenced by any specific urban runoff event. Data on wet weather water quality conditions were obtained from previous studies. Dry weather concentrations of many constituents exceeded expected wet weather concentrations by factors of two to five times. For example, during dry weather, many of the major constituents (e.g., major ions, total solids, etc.) were significantly greater in both the urban and nonurban reaches. These constituents were all found in substantially lower concentrations in the urban runoff and in the rain. The rain and the resultant runoff apparently diluted the concentrations of these constituents in the creek during wet weather. Within the urban area, many constituents were found in greater concentrations during wet weather than during dry weather (Chemical Oxygen Demand, organic nitrogen, and especially heavy metals - lead, zinc, copper, cadmium, mercury, iron, and nickel). Similar differences between wet and dry weather were also noted for the nonurban area. However, the wet weather concentrations were typically much higher in the urban area than in the nonurban area.

Lead concentrations were found to be more than seven times as great in the urban reach than in the nonurban reach during dry weather, with a confidence level of 75 percent. Other significant increases in urban area concentrations occurred for nitrogen, chloride, orthophosphate, Chemical Oxygen Demand, specific conductance, sulfate, and zinc. The dissolved oxygen measurements were about 20 percent less in the urban reach than in the nonurban reach of the creek.

Lead concentrations exceeded the water quality criteria for both livestock and aquatic life uses. During dry weather, the water was also hard to very hard (typical of local surface and ground waters). Chloride concentrations at the furthest downstream station (Dixon) were high, due to tidal influences (mixing with San Francisco Bay water). About half of the observed ammonia values were equal to or greater than the established criteria for aquatic life (0.02 mg/l). Total coliform bacteria populations were also high at most of the sampling sites. Water quality upstream of the urbanized area was fairly consistent from site to site, and the quality changed markedly as the creek passed through the urbanized area.

Selected wet weather samples were also analysed for "priority" pollutants in a special substudy.

Coyote Creek Sediment Quality

Lead concentrations in the urban area sediments were greater than those from the nonurban area by a factor of about six times (which was the largest increase for any constituent monitored). Large differences were also found between the urban and nonurban area data for both sulfate and phosphate concentrations. Average zinc concentrations in the sediments were found to increase by only about 1.5 times, but with a high degree of confidence.

During the first survey, the differences between urban and nonurban sediment concentrations were much greater; sulfur, lead, and arsenic were found to have substantially greater concentrations (4 to 60 times greater) in the urban area sediments than in the nonurban sediments. Seasonal and yearly changes in sediment concentration differences between the urban and nonurban creek reaches were therefore important.

Selected sediment samples were also analysed for many elements using mass spectrographic procedures. Other sediment samples were also analysed for priority pollutants.

The ratio of sediment concentrations (mg/kg) to water concentrations (mg/l) was also calculated. This S/W ratio would be low for readily-soluble constituents and it would be high for relatively insoluble constituents. The S/W ratios were found to be very large for most of the constituents monitored. The largest difference between urban and nonurban area S/W ratios was for lead, where the S/W ratio was over 3000 for the urban area and only about 400 for the nonurban area. The total Kjeldahl nitrogen S/W ratio was about 5500 for the urban area but exceeded 22,000 for the nonurban area. For the other constituents studied, the differences between the urban and nonurban area S/W ratios was much less. Urban runoff constituents could be present in the creek water column at acceptable concentrations, despite the fact that the interstitial waters in the sediments may be polluted. Unfortunately, little information is available concerning the effects of polluted sediments on benthic organisms.

Bioaccumulation of Lead and Zinc in Selected Coyote Creek Organisms

Some evidence of bioaccumulation of lead and zinc was found in many of the samples of algae, crayfish, and cattails. The measured concentrations of the metals in the organisms exceeded concentrations in the sediments by a maximum factor of about six. Concentrations of lead and zinc in the organisms exceeded water column concentrations by factors of about 100 to 500. Lead concentrations in urban area samples of algae, crayfish, and cattails were found to be two to three times as high as in nonurban area samples, whereas zinc concentrations in urban area algae and cattail samples were about three times as high as the concentrations in the samples from the nonurban areas. Lead and zinc concentrations in fish tissue were not noticeably different between the urban and nonurban area samples.

Fish Found in Coyote Creek

Introduced fishes often cause radical changes in the nature of the fish fauna present in a given waterbody. In many cases, they become the dominant fishes because they are able to out-compete the native fishes for food or space, or they may possess greater tolerance to environmental stress. In general, introduced species are most abundant in aquatic habitats modified by man while native fishes tend to persist mostly in undisturbed areas. Such is apparently the case within Coyote Creek.

Samples from the nonurban portion of the study area were dominated by an assemblage of native fish species such as hitch, threespine stickleback, Sacramento sucker, and prickly sculpin. Rainbow trout, riffle sculpin, and Sacramento squawfish were captured only in the headwater reaches and tributary streams of Coyote Creek. Collectively, native species comprised 89 percent of the number and 79 percent of the biomass of the 2379 fishes collected from the upper reaches of the study area. In contrast, native species accounted for only seven percent of the number and 31 percent of the biomass of the 2899 fishes collected from the urban reach of the study area.

Hitch was the most numerous native fish species present. Hitch generally exhibit a preference for quiet water habitat and are characteristic of warm, low elevation lakes, sloughs, sluggish rivers and ponds. Mosquitofish dominated the collections from the urbanized section of the creek and accounted for over two-thirds of the total number of fish collected from that area. This fish is particularly well-adapted to withstand extreme environmental conditions, including those imposed by stagnant waters with low dissolved oxygen concentrations and elevated temperatures. The second most abundant fish species in the urbanized reach of Coyote Creek, the fathead minnow, is equally well suited to tolerate extreme environmental conditions. The species can withstand low dissolved oxygen, high temperature, high organic pollution and high alkalinities. Often thriving in unstable environments such as intermittent streams, the fathead minnow can survive in a wide variety of habitats.

Benthic Macroinvertebrates Observed in Coyote Creek

In general, the abundance and diversity of taxa appear to be greatest in the nonurbanized sections of the stream. The overall increase in number and diversity of benthic organisms encountered in the 1979 samples as compared to the 1978 samples may be attributed to further recovery from the drought conditions that preceded this study. The benthos in the upper reaches of the creek consisted primarily of amphipods and a diverse assemblage of aquatic insects. Together those groups comprised two-thirds of the benthos collected from the nonurban portion of the creek. Clean water forms were abundant and included amphipods (*Hyaella azteca*) and various genera of mayflies, caddisflies, black flies, crane flies, alderflies, and riffle beetles. In contrast, the benthos of the urban reaches of the creek consisted almost exclusively of pollution tolerant oligochaete worms (tubificids). Tubificids accounted for 97 percent of the benthos collected from the lower portion of Coyote Creek.

Coyote Creek Summary

The biological investigations in Coyote Creek indicated distinct differences in the taxonomic composition and relative abundance of the aquatic biota present in Coyote Creek. The nonurban sections of the creek support a comparatively diverse assemblage of aquatic organisms including an abundance of native fishes and numerous benthic macroinvertebrate taxa. In contrast, the urban portions of the creek comprise an aquatic community generally lacking in diversity and is dominated by pollution-tolerant organisms such as mosquitofish and tubificid worms.

Although certain differences in physical habitat occur in the downstream reaches of the study area (e.g., a decrease in stream gradient, shorter riffles, wider, deeper pools, etc.), such differences are not thought to be responsible for the magnitude of change noted in the aquatic biota of the urban reach of Coyote Creek. Urban runoff has been shown to significantly increase the levels of many toxic materials in the receiving water and sediments of the stream.

No one pollutant appears to be responsible for the significant decrease in aquatic life abundance and diversity observed in Coyote Creek as it passes through San Jose. Very large concentrations of several toxic pollutants in the sediments were observed but they cannot be conveniently related to water quality criteria or published test results on water quality effects. The reported water quality criteria for aquatic organisms present in Coyote Creek do not consider antagonisms or synergisms that are likely to occur, except for the antagonistic effect of hardness on heavy metal toxicity. A combination of effects of various heavy metals can, in many cases, be greater than the effects of each one individually. Some of the constituents observed that are likely to create water quality problems occur in potential problem concentrations in both the nonurban and urban reaches of Coyote Creek (temperature, ammonia, nitrates, phosphorus, and mercury). The most important constituents in the urban area that exceeded criteria, which are not exceeded in the nonurban area, include dissolved oxygen, copper and lead. Zinc concentrations exceeded the water quality criteria in both the urban and nonurban areas, but the urban zinc concentrations exceeded the criteria by a much greater amount.

Changes in the nature of the stream substrate also occur as a result of the deposition of silt and debris which originate from urban runoff. Such changes are likely to be a primary reason for the decline in species abundance and diversity in the urban reaches of Coyote Creek.

BELLEVUE URBAN RUNOFF STUDY

Pitt and Bissonnette [9] summarized the many aspects of urban runoff in Bellevue, Washington that were recently studied during a four year program funded by the EPA (Corvallis Lab, Storm and Combined Sewer Section, and the Water Planning Division - NURP). The University of Washington [10,11,12,13,14] conducted a series of studies to contrast the biological and chemical conditions in urban Kelsey Creek with rural Bear Creek. The urban creek was significantly degraded when compared to the rural creek, but still supported a productive, but limited and unhealthy salmonid fishery. Many of the fish in the urban creek, however, had respiratory anomalies. The urban creek was not grossly polluted, but flooding from urban developments has increased dramatically in recent years. These increased flows have dramatically changed the urban stream's channel, by causing unstable conditions with increased stream bed movement, and by altering the availability of food for the aquatic organisms. The aquatic organisms are very dependent on the few relatively undisturbed reaches. Dissolved oxygen concentrations in the sediments depressed embryo salmon survival in the urban creek. Various organic and metallic priority pollutants were discharged to the urban creek, but most of them were apparently carried through the creek system by the high storm flows to Lake Washington.

The U.S. Geological Survey (USGS) [15,16] intensively monitored urban runoff quality and quantity from three residential areas in Bellevue. Wet and dry atmospheric sources were also monitored by the USGS. The runoff quality was found to be much cleaner than found in other locations in the U.S.

The Municipality of Metropolitan Seattle (METRO) [17] analysed many source area, urban runoff, and creek samples for metallic and organic priority pollutants. Concentrations in the creeks and in urban runoff were low, but source area samples had high concentrations of more priority pollutants. PAHs and phthalate esters were most commonly detected in the samples.

The City of Bellevue [18] collected and analysed urban runoff and baseflow samples using flow-weighted techniques from more than 300 storms from two residential areas, in addition to extensively evaluating street and sewerage cleaning.

Bellevue Beneficial Uses and Urban Runoff Problems

Bellevue area waters, including Kelsey Creek (the urban creek studied), have five beneficial uses. These beneficial uses are as follows:

1) preservation of habitat suitable for aquatic organisms
2) flood prevention by the conveyance of stormwater
3) open space and resource preservation
4) recreational uses (swimming and boating)
5) aesthetics.

All of these beneficial uses were found to be degraded, to various extents, in Kelsey Creek. The following discussion summarizes these problems.

Degradation of Habitat, Observations. The urbanized Kelsey Creek environmental quality was much better than expected, but was degraded when compared to the less urbanized Bear Creek. Kelsey Creek apparently lacked gross contamination by pollutants. The direct toxic effects of pollutants during storms appeared to be small; the stream did support a small, but unhealthy, salmon population.

The fish population in Kelsey Creek had adapted to its degrading environment by shifting the species composition from coho salmon to less sensitive cutthroat trout and by making extensive use of less disturbed refuge areas. Studies of damaged gills found that up to three-fourths of the fish in Kelsey Creek were affected with respiratory anomalies, while no cutthroat trout and only two of the coho salmon sampled in Bear Creek had damaged gills. Massive fish kills in Kelsey Creek and its tributaries were observed on several occasions during the project due to the dumping of toxic materials down the storm drains.

There were significant differences in the numbers and types of benthic organisms found. Mayflies, stoneflies, caddisflies, and beetles were rarely observed in Kelsey Creek but were quite abundant in Bear Creek. These organisms are commonly regarded as sensitive indicators to environmental degradation. As an example of a degraded aquatic habitat in Kelsey Creek, a specie of clams (Unionidae) was not found in Kelsey Creek, but was found in Bear Creek. These clams are very sensitive to heavy siltation and unstable sediments. Empty clam shells, however, were found buried in the Kelsey Creek sediments indicating their previous presence in the creek and their inability to adjust to the changing conditions. The benthic organism composition in Kelsey Creek varied radically with time and place while the organisms were much more stable in Bear Creek.

Degradation of Habitat, Possible Causes. These aquatic organism differences were probably mostly associated with the increased peak flows in Kelsey Creek caused by urbanization and the resultant increase in sediment carrying capacity and channel instability of the creek. There was also the potential for accumulation of toxic materials in the stream system affecting aquatic organisms; but only low concentrations of toxic materials were found in the receiving waters.

The concentrations of dissolved oxygen in the urban creek's gravel waters were quite low and may have decreased the survival of salmon embryos. Instream embryo bioassays indicated that coho embryo salmon survival was significantly greater in Bear Creek than in Kelsey Creek, but no difference was found when using rainbow trout embryos.

Direct receiving water effects from the urban runoff may not have been significant for most storms. Potential long term problems, however, may have been associated with settleable solids, lead, and zinc. These settled materials may have silted up spawning beds and introduced high concentrations of potentially toxic materials directly to the sediments. The oxygen depletion observed in the interstitial waters was probably caused by organic sediment buildup from runoff events.

Kelsey Creek had much lower flows than Bear Creek during periods between storms. About 30 percent less water was available in Kelsey Creek during the summers. These low flows may also have significantly affected the aquatic habitat and the ability of the urban creek to flush toxic spills or other dry weather pollutants from the creek system.

Kelsey Creek had higher water temperatures (probably due to reduced shading) than Bear Creek. This probably caused the faster fish growth in Kelsey Creek.

Conveyance of Stormwater. Kelsey Creek had extreme hydrologic responses to storms. Flooding substantially increased in Kelsey Creek during the period of urban development; the peak annual discharges almost doubled in the last 30 years, and the flooding frequency also increased due to urbanization. These increased flows in urbanized Kelsey Creek resulted in greatly increased sediment transport and channel instability.

Open Space and Resource Preservation Beneficial Uses. The lack of adequate buffer zones and natural creek banks along much of the urban reaches of Kelsey Creek is balanced by extensive park system developments along selected reaches. Natural creek reaches are very important for the aquatic organisms in Kelsey Creek. Creek bank-side homeowners have been allowed to make extensive channel and riparian vegetative changes which significantly reduced the ability of the creek to support aquatic life.

Recreational Beneficial Uses. The natural small size of Kelsey Creek restricts its usefulness for most water contact related activities. The fecal coliform bacteria populations in Kelsey Creek were high, and variable. These organisms indicate the potential presence of pathogenic bacteria and commonly exceeded water contact numeric criteria.

Aesthetics Beneficial Uses. This use is related to most of the above uses; unsightly creeks are not utilized in educational field trips or as swimming areas. Dead fish from periodic toxic material spills significantly degrade this use. Debris and unstable channels also adversely affect the aesthetic quality of Kelsey Creek.

Bellevue Summary

These Bellevue studies indicated the very significant interrelationships between the physical, biological, and chemical characteristics of the urbanized Kelsey Creek system. The aquatic life beneficial uses were found to be impaired and stormwater conveyance was found to be significantly stressed by urbanization. These degradations were most likely associated with increased flows from the impervious areas in the urban area. Changes in the flow characteristics could radically alter the ability of the stream to carry the polluted sediments into the other receiving waters. If the stream power (sediment carrying capacity) of Kelsey Creek was reduced, then these toxic materials could be expected to be settled into its sediment, with increased effects on the stream's aquatic life. Reducing peak flows would also reduce the flushing of smaller fish and other aquatic organisms from the system.

It was found that substantial quantities of water originated from the impervious areas in the developed areas. More careful planning to increase the perviousness of these areas should also be considered.

An important recommendation is to preserve the remaining refuge areas in Kelsey Creek and to carefully design any channelization project to include refuge areas for the aquatic life. Because of the larger potential for sedimentation of toxic pollutants in Kelsey Creek, increased awareness of the beneficial uses and undesirable discharges to the drainage system will be more important. The large assimilative capacity of the water bodies that currently receive most of these pollutants are currently masking this concern.

CONCLUSIONS

The effects of urban runoff on receiving water aquatic organisms or other beneficial uses is very site specific. Different land development practices may create substantially different runoff flows. Different rain patterns cause different particulate washoff, transport, and dilution conditions. Local attitudes also define specific beneficial uses and desired controls. There is also a wide variety of water types receiving urban runoff, and these waters all have watersheds that are urbanized to various degrees. Therefore, it is not suprising that urban runoff effects are also quite variable and site specific.

Previous attempts to identify urban runoff problems using existing data have not been conclusive because of differences in sampling procedures and the common practice of pooling data from various sites, or conditions. It is therefore necessary to carefully design comprehensive, long-term studies to investigate urban runoff problems on a site specific basis. Sediment transport, deposition, and chemistry play key roles in urban receiving waters and need additional research. Receiving water aquatic biological conditions, especially compared to unaffected receiving waters, should be studied in preference to laboratory bioassays.

These specific studies need to examine beneficial uses directly, and not rely on published water quality criteria and water column measurements alone. Published criteria are usually not applicable to urban runoff because of the slug nature of urban runoff and the unique chemical speciation of its componants.

The two West Coast studies summarized in this paper both found significant aquatic life beneficial use impairments in urban creeks, but the possible causes were quite different. The Coyote Creek study found major accumulations of toxic sediments in the urban reaches of the creek, while the Bellevue study found very little toxic material in the sediments. The Bellevue urban creek had a very large carrying capacity for sediment and high flow rates which apparantly flushed the toxic sediments through the creek and into Lake Washington. Fish kills were observed in Bellevue, but they were associated with illegal storm drain discharges during dry weather.

The long-term aquatic life effects of urban runoff are probably more important than short-term effects associated with specific events. The long-term effects are probably related to the deposition and accumulation of toxic sediments, or the inability of the aquatic organisms to adjust to repeated exposures to high concentrations of toxic materials or high flow rates.

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TRENDS IN URBAN WATER QUALITY DURING STORM EVENTS

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INTRODUCTION

In order to manage an urban stream and its surrounding watershed, it is important to recognize non-point sources of pollutants, i.e., urban runoff. Urban runoff has a unique set of characteristics which reflect the surrounding watershed's usage, geology, season, rain intensity, etc. To understand its characteristics and its impact, in stream water quality must be monitored.

During the summer of 1983, Pollution Control at Southern Illinois University (SIU) in Carbondale, Illinois, monitored Piles Fork Creek, which transects Carbondale, during a torrential storm. This storm ended a 24 day dry period. Samples were obtained throughout the rise and fall of the stream's discharge. Results are expressed in mg/l and lbs/day.

BACKGROUND

The 7 sq. mile watershed surrounding Piles Fork Creek, within the study area, is composed of 72Δ non-urbanized land, consisting primarily of agricultural, forest and park areas. Urbanized areas represent 28Δ of the watershed. This portion of land is characterized by commercial and residential uses.

Piles Fork Creek originates 2 miles south of Carbondale city limits. Prior to entering the city, the stream creates Carbondale Reservoir. The stream is then reformed, via overflow and continues through the city.

This first order stream has undergone mild channelization. No major point source discharges enter within the study area. The landscape is gently sloping and soils are composed of various silt-clay soil series.

METHODS

Piles Fork Creek has been monitored by the SIU Department of Pollution Control for approximately one year to acquire baseline water quality information. The data generated represents water quality of the stream before entering Carbondale and after passing through the city.

Rain sampling occurred on July 24, 1983, when Carbondale received a sudden storm. The city received 0.90 inches of rain within a 2 hour period. During this time rain intensity was calculated at 0.90 inches of rain per hour.

Monitoring of water quality within the creek began 15 minutes from the initiation of the rain. Samples were taken at every 1 foot change in flow level for a 2.5 hour period. Ten grab samples were obtained. The tenth sample was acquired 16 hours after the storm event.

During all sampling, dissolved oxygen, temperature, conductivity and velocity were obtained in the field. Velocity measurements were taken with a velocity meter, designed for low flows or by using velocity and adjusting by a factor of 0.8 to acquire average velocity with the stream [2].

Channel profiles were constructed during each sampling event to observe any changes in channel configuration and to calculate discharge. Weather information was provided from the Horticulture Center Weather Station at SIU-C.

Analysis of water quality consisted of pH, alkalinity (alk), chlorides (Cl-), biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), volatile suspended solids (VSS), total solids (TS), total volatile solids (TVS), ammonia (NH3-), nitrates (NO3-), ortho-phosphates (O-PO4) and fecal coliform. Samples were preserved for COD, NH3- and NO3- at the sites upon collection. Samples were frozen for ortho-phosphates. All analysis was done in accordance with Standards Methods, 15th ed. [1].

RESULTS

Discharge (Q) ranged from 253 cubic ft/sec to 19 cubic ft/sec. Maximum discharge was reached within 40 minutes of rainfall initiation. The average storm value for discharge was 117 cubic ft/sec, contrasting with a base flow discharge of 3 cubic ft/sec. Refer to Graph 1.

Concentrations of parameters, fecal coliform, total solids, total volatile solids and volatile suspended solids all demonstrated first flush characteristics. Graph 2 represents the typical graph for the above mentioned parameters. Biological oxygen demand, chemical oxygen demand, ammonia and suspended solids all peaked within 40 minutes of the storm's beginning. Ortho-phosphate concentration peaked 90 minutes into the storm. Refer to Graph 3.

Ranges of concentrations and their comparison to base line data are contained in Table 1.

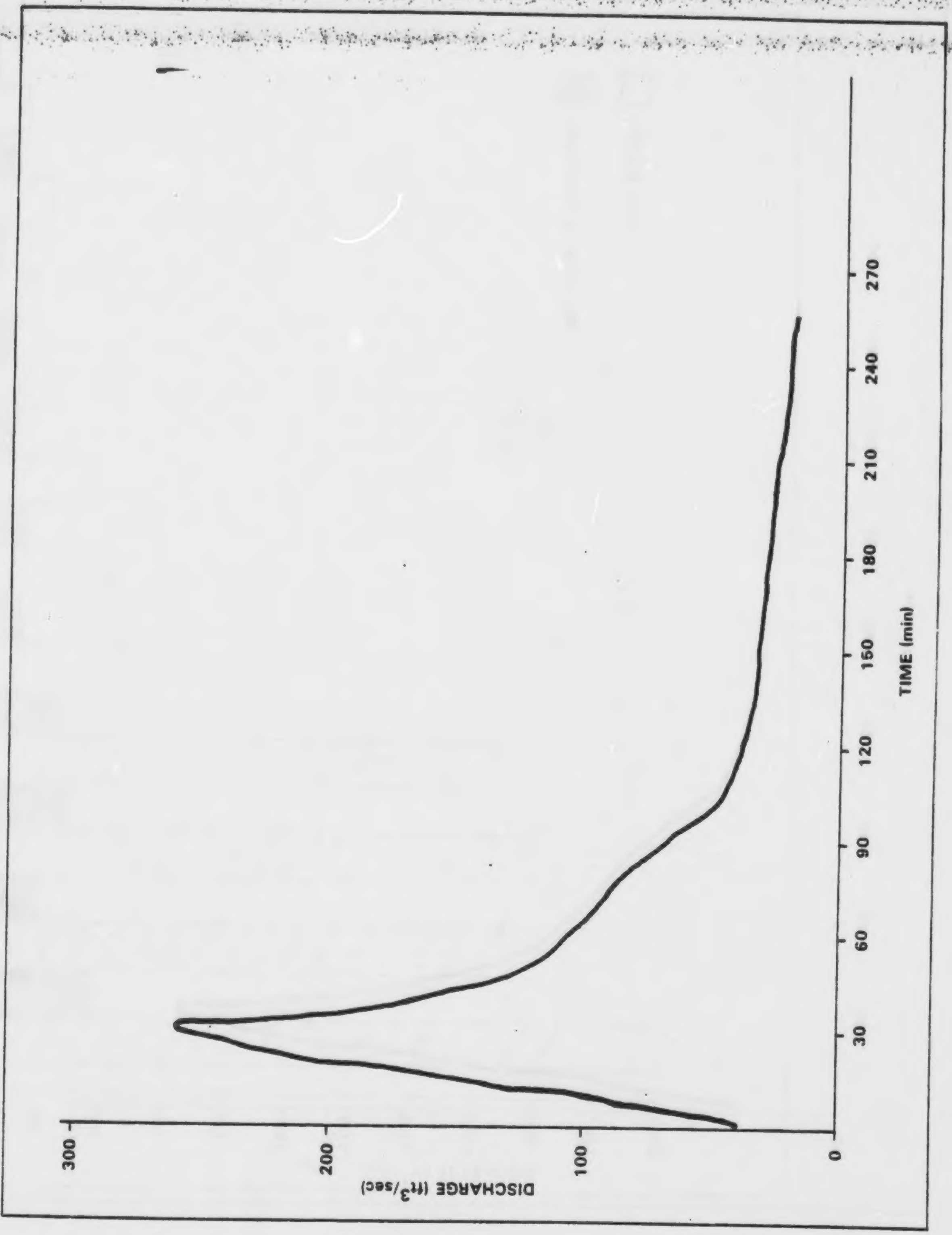

Figure 1. Discharge (cubic ft./sec.) vs. Time

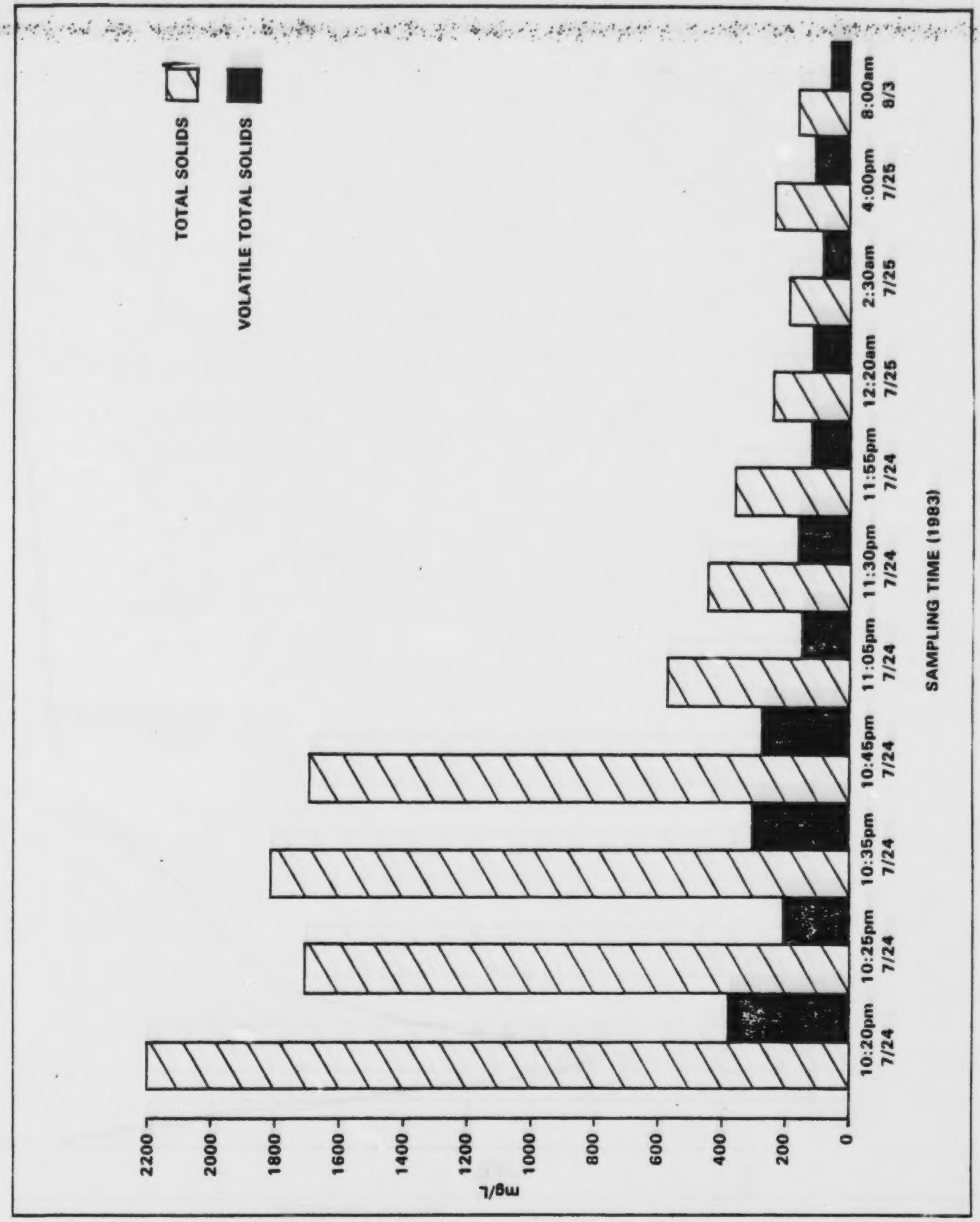

Figure 2. Concentration of Total Solids and Volatile Solds vs. Sampling Time

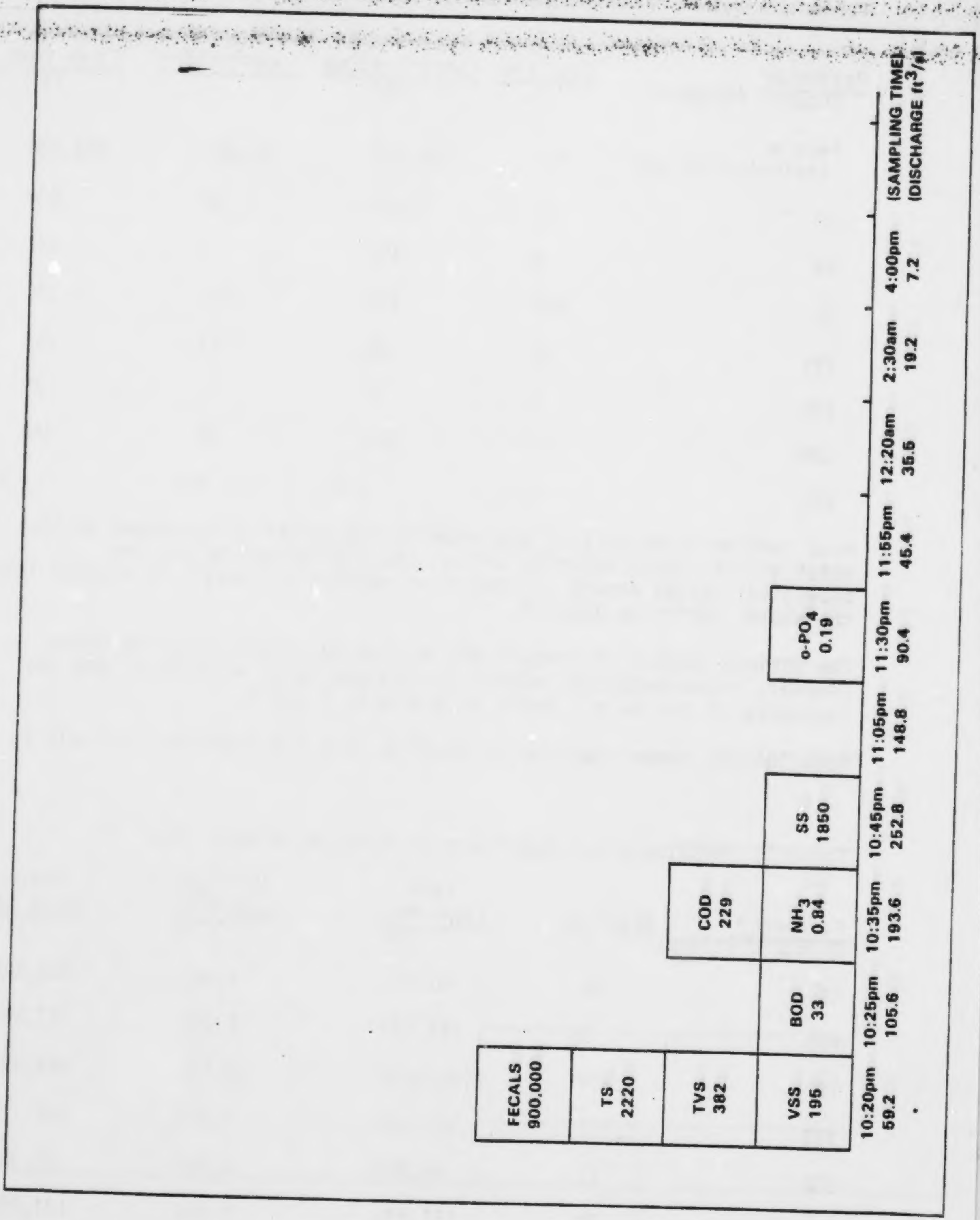

Figure 3. Peak Concentration of Parameters (mg/l) During Rain Event

Table 1. Concentration Comparison of Baseline Mg/L to Rain Data

Parameter Q(cubic ft/sec)	Baseline 3	Peak Storm Concentration 253	Minimum Storm Concentration 7	Average Storm Conc. 117
fecals (colonies/100 ml)	755	900,000	23,000	650,000
SS	14	1,850	12	874
VSS	6	195	6	111
TS	157	220	193	1,140
TVS	53	382	73	214
BOD	1	33	13	29
COD	2	229	53	144
NH_3	0.5	0.8	0.3	0.6

Mass loadings (lbs/day) of suspended solids, volatile suspended solids, total solids, total volatile solids, chemical oxygen demand and biological oxygen demand all peaked at maximum discharge, 40 minutes into the storm. Refer to Graph 4.

The maximum loading of ammonia was reached 30 minutes into the storm. However, ortho-phosphate reached its maximum level 90 minutes from the beginning of the storm. Refer to Graphs 5, 6 and 7.

Mass loading ranges compared to baseline data are presented in Table 2.

Table 2. Mass Loading Comparisons of Baseline to Rain Data

Parameter Q (cubic ft/sec)	Baseline 3	Peak Storm Mass 253	Minimum Storm Mass 19	Average Storm Mass 117
SS	32	2,520,975	4,967	698,696
VSS	9	244,534	1,257	87,362
TS	3,385	2,312,482	19,972	843,027
TVS	1,151	396,998	8,872	146,109
BOD	11	44,969	1,345	18,521
COD	32	262,999	6,519	101,081
NH_3	19	877	42	405

Note: In reference to graphs shown, sampling time "8/3" represents baseline data used in comparison with rain data obtained 7/24 through 7/25. The abbreviation RS_1, RS_2, etc. represent consecutive samplings during the rain event.

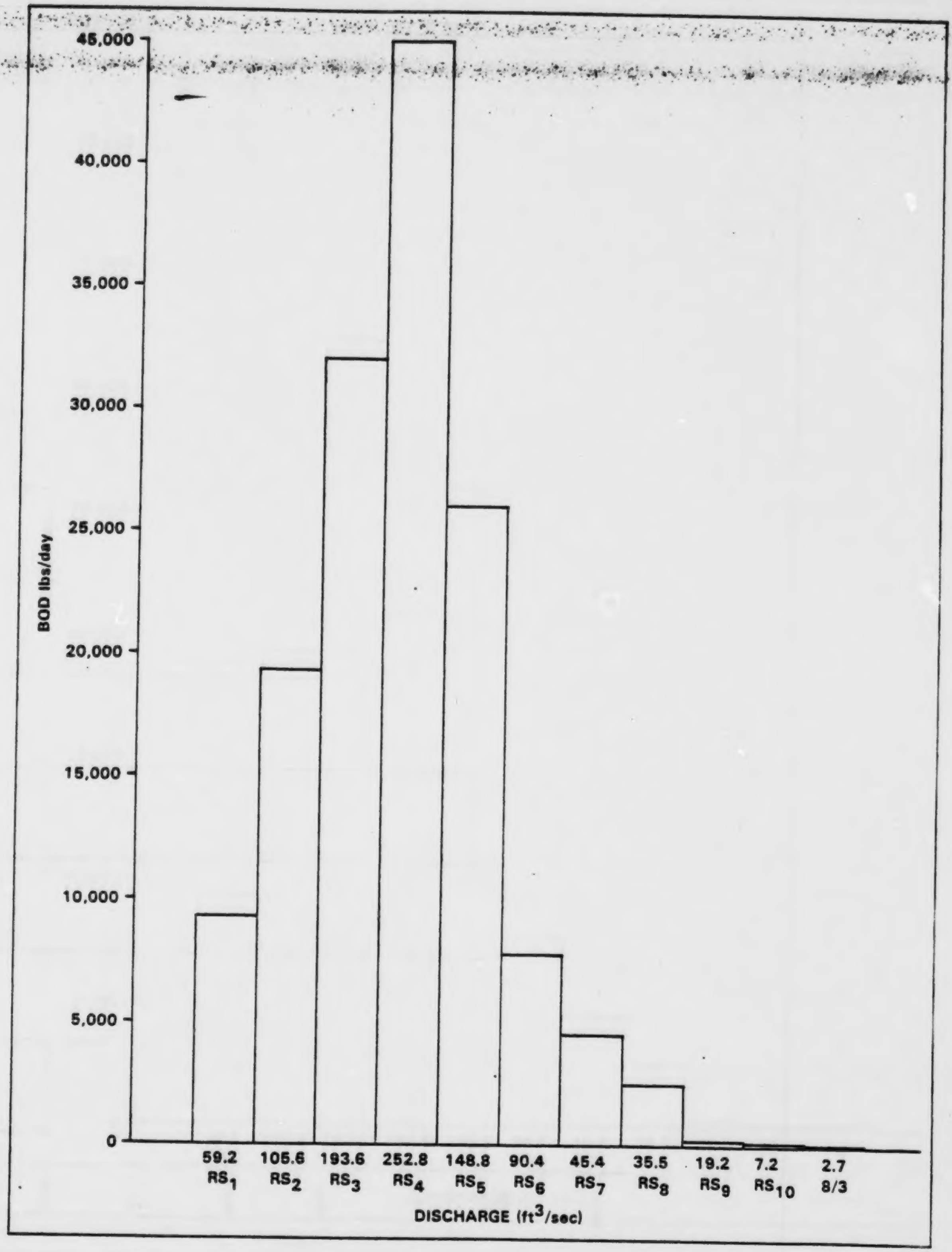

Figure 4. BOD (lbs./day) vs. Discharge (cubic ft./sec.)

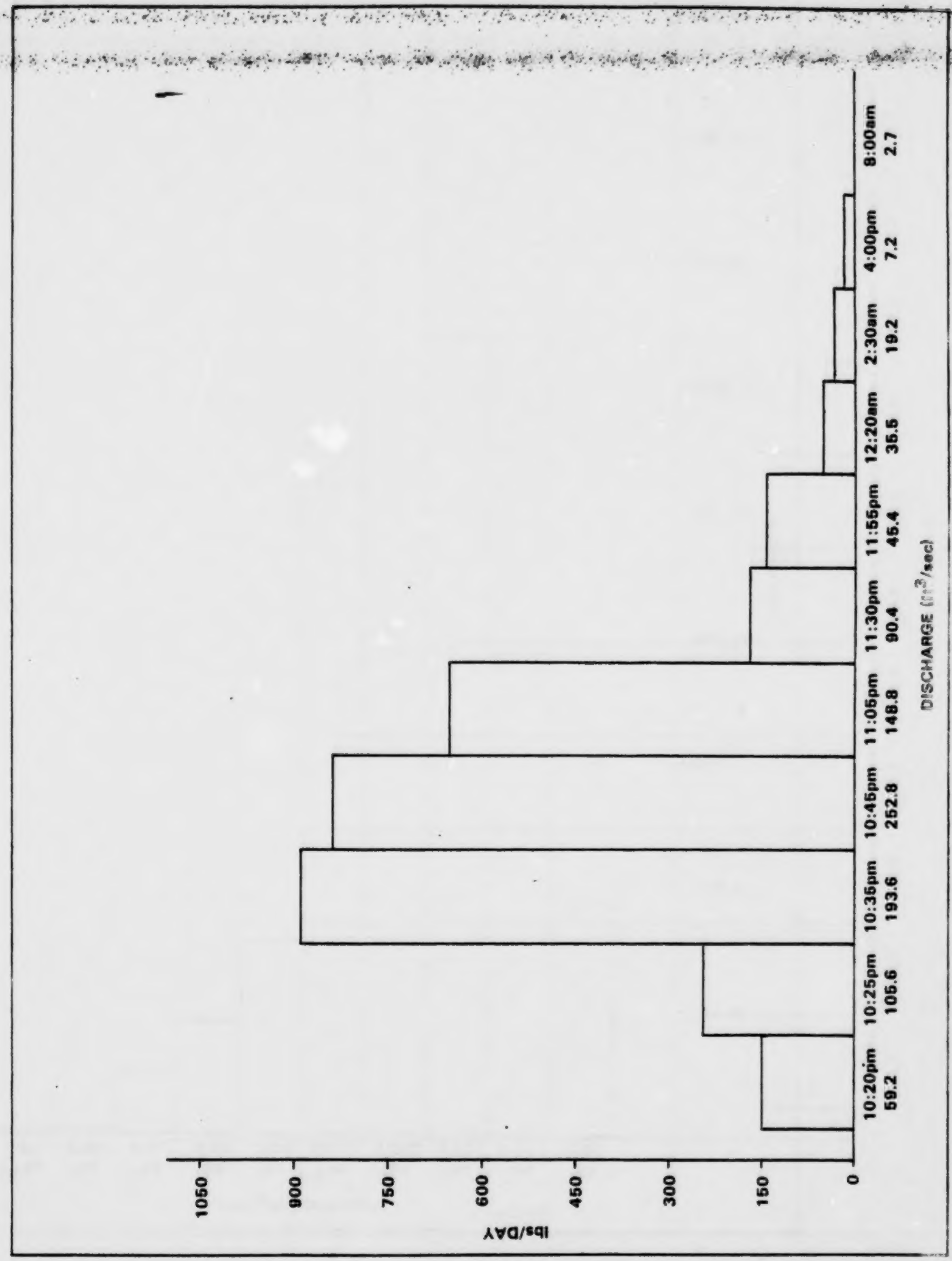

Figure 5. Ammonia (lbs./day) vs. Discharge

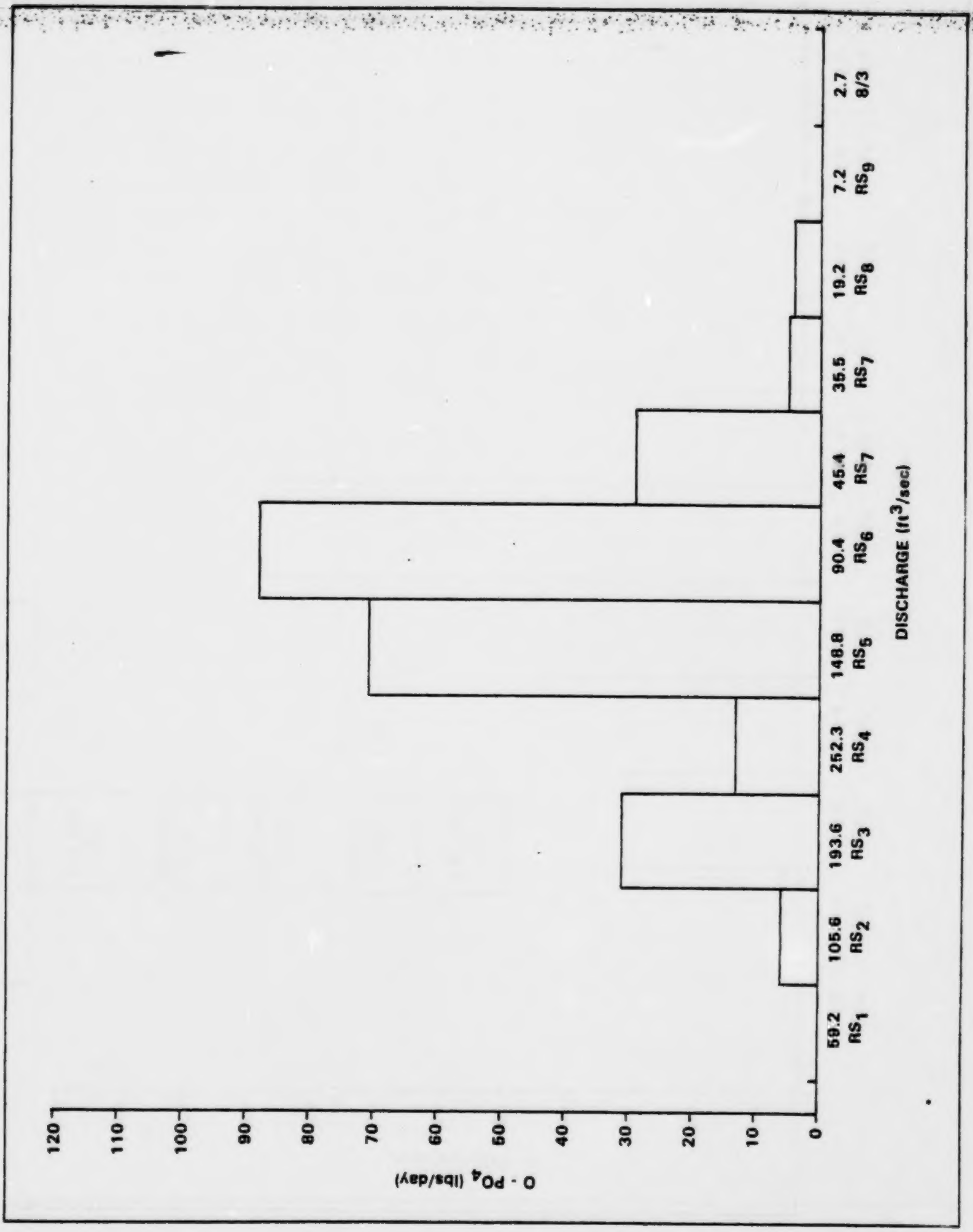

Figure 6. O-PO_4 (lbs./day) vs. Discharge (cubic ft./sec.)

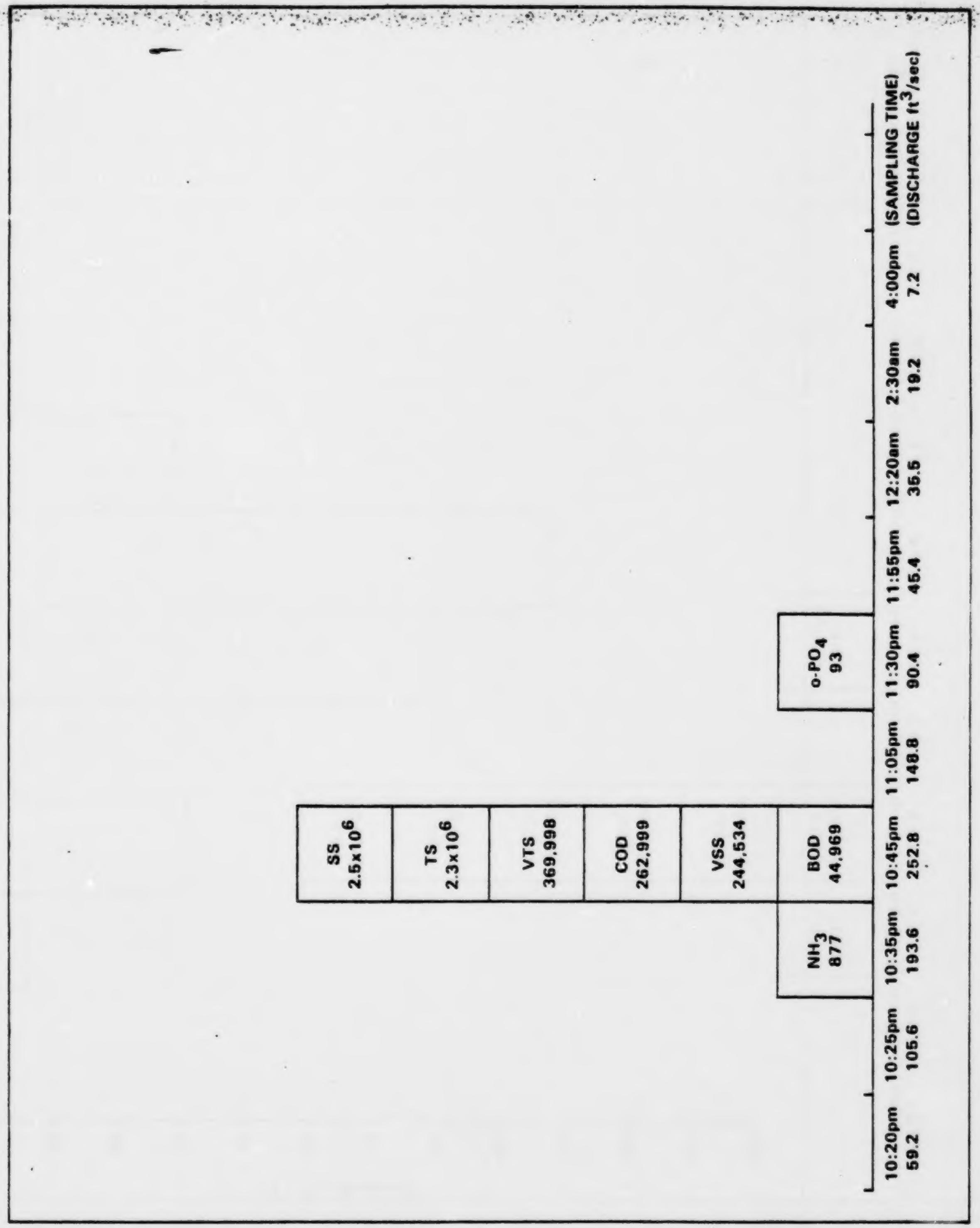

Figure 7. Peak Mass Loadings of Parameters (lbs./day) During Rain Event

DISCUSSION

Management of urban streams and their surrounding watersheds require examination of in stream water quality. This process involves identification of potential sources of contamination and determining the magnitude of their effect on the receiving water body. Non-point sources, i.e., urban runoff must be considered within this process.

Understanding the dynamics of urban runoff is necessay in order to evaluate potential impact. Characteristics which define the quality of urban runoff are intrinsic to the individual watershed and vary throughout the duration of runoff.

Therefore, management discussions concerning an urban stream and watershed rely on observing that stream system throughout the runoff event. Specifically, it is important to monitor the changes in water quality at various stages during the rise and fall of the stream's discharge.

Once samples have been obtained and analyzed, interpretation will depend not only on the constraints of the monitoring conditions but also on the manipulation of the data.

Parameters expressed in mg/l often demonstrate strong first flush tendencies. This will depend on the proximity of pollutants and mode of travel. The dissolved parameters, ortho-phosphates and ammonia peak later in the storm. Refer to Graph 3.

Within this type of expression (mg/l) the factor of dilution is intrinsic. Therefore, to quantify the amount of pollutants contributed from the watershed or the amount being transferred into a receiving body, mass loadings (lbs/day) must be evaluated.

These results take into account the quantity of water being moved through the system. This information compares with mg/l data in that first flush trends are not noted. Most parameters peak at times when discharge was at its peak. Refer to Graph 7.

Quantities of pollutants expressed in terms of pounds received during the storm and pounds per urban acre give perspective to the amounts of pollutants contributed. This information is useful, considering results expressed in mg/l are generally relatively slight and results expressed in lbs/day are often staggering in their magnitude. Refer to Table 3. This is exemplified in that BOD maximized at 33 mg/l and mass loadings peaked at approximately 45,000 lbs/day. However, the mass loading received during the storm was calculated at 1,800 pounds and mass contributed per urban acre was calculated at 8 pounds.

Table 3. Average Amount of Pollutants Observed During Storm

Parameter	Average (lbs/day)	Lbs Received During Storm	lbs/acre	lbs/sq ft
SS	698,696	67,832	55	$1.0x10^{-3}$
VSS	87,362	8,481	7	$2.0x10^{-4}$
TS	843,027	81,844	66	$2.0x10^{-3}$
VTS	146,109	14,185	11	$3.0x10^{-4}$
BOD	18,521	1,799	2	$3.0x10^{-5}$
COD	101,081	9,813	8	$2.0x10^{-5}$
O-PO4	31.2	3.0	$2.4x10^{-3}$	$5.6x10^{-8}$
NH3	404.9	39.3	$3.2x10^{-2}$	$7.0x10^{-7}$

CONCLUSION

Effective management of an urban stream and watershed begin with the identification of potential pollutant sources. Within this process, urban runoff must be recognized as a contributing factor to urban stream quality.

The extent of impact from urban runoff is quantified through the monitoring program. This program, in order to reflect the dynamic nature of runoff water quality, must acquire samples throughout the duration of runoff.

Once this is achieved, interpretation of the data will lead to the assessment of impact. Different modes of data expression, mass loadings and concentrations, are important to consider. When viewed separately, these numerical expressions will derive different information and thus different interpretations.

This data base will provide information identifying magnitude of impact and hydrolysis characteristics. In addition, this information will assist in designing a regular monitoring program, and for future data interpretation.

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SESSION 1-B: MODELING AND QUANTITY ISSUES

REFLECTIONS ON EUROPEAN AND AMERICAN STORMWATER MODELING

by

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INTRODUCTION

In this talk I will try to give some idea, from my observation, on the current Western European practice, philosophy, and trends in storm water modeling. (In this talk I exclude myself from discussion of rainfall modeling.) Reflecting from this observation we may see if we can learn something from them. Like us, they have their strong and weak points. They know our development on storm water modeling fairly well. Conversely, I feel we are a little bit isolated from the rest of the world in this field. It seems we can look inside of the country and we know quite well what is going on in the States. But we are quite ignorant on what is going on at the other side of the Atlantic Ocean.

I have been lucky that I maintain a regular contact with Western European engineers. In the following I will first briefly introduce a few select models, then I will give my observations.

SOME EUROPEAN MODELS

There are quite a few models at the other side of the ocean, although not as many as at this side. It is not possible for me to give a comprehensive introduction on their models. I don't think I know all of them. Therefore, I select briefly four major models which we should pay attention to. They are all water quantity models without water quality consideration.

The first one is the British Transport and Road Research Laboratory (TRRL) Model. It is known in this country by its old name, the Road Research Laboratory (RRL) Model. I use the name which is used in United Kingdom. It is perhaps the best known European model in this country because ILLUDAS was more or less modeled after the TRRL model. There was a good interface between the industry and the researchers in Great Britain during the development and implementation stages of the model. It was widely used in Britain after its introduction in 1962 (1,2). It is basically a linear kinematic wave sewer flow routing model, that is, it uses Darcy-Weisbach's steady flow equation together with Colebrook-White resistance formula to perform a stepwise steady flow routing adjusted for pipe storage. It is not a high accuracy model and it cannot account for downstream backwater effect. On the land surface it considers only the runoff from directly contributing impervious surfaces. The TRRL method most of the people in North America know is the original version.

By early 1970's there was a demand from British engineers to improve the TRRL model or to develop a new, improved hydraulic model. They went both ways. The new model is the Wallingford Package which will be described later. The revision was the Second Edition of TRRL released in 1976 (3). The major improvement includes a linear reservoir conceptual scheme to simulate the runoff contribution from pervious and impervious overland surface and a modification on the pipe storage computation. The revised edition did not really get popular because a short while later in 1979 the Wallingford Package was introduced.

What we should learn from TRRL model is the coordination between the government, industry and research institutes in its development and successful adoption.

The second model I want to mention is called the Wallingford Package (4, 5, 6). It is the result of the British Working Party on the Hydraulic Design of Storm Sewers. It is the standard sewer design method to be used in Great Britain. However, it is an expensive one to use in terms of the right to use it. It is a good package consisting of four modulars: (a) Modified rational method for sizing sewers; (b) A modular to simulate the time dependent sewer flow using a modified kinematic wave technique called Muskingum-Cunge method for the gravity flow and stepwise steady pipe network for surcharge flow; the gravity flow routing scheme cannot account for the downstream backwater effect; (c) A modular based on inflow hydrographs to size sewer pipes and/or simulates discharge hydrographs including pumping stations; and (d) a least-cost optimal design method to design the size and slope of the sewers incorporating with the modified rational method.

Among the European models perhaps this one, together with the original version of TRRL and the misunderstood Dorsch Consult HVM model were the only ones that were introduced to North Americans. It was introduced here in Urbana in 1981 at the pre-conference workshop of the Second International Conference on Urban Storm Drainage. In that workshop the computer programs of four different models were loaded in the University of Illinois computer system so that the participants could obtain first-hand experience of the models by applying their own sewer systems to any of the models to test their results or to design if they wished. The four models loaded into the computer were the Wallingford Package, SWMM, ILSD, and ILLUDAS.

Like the TRRL model, the development, testing, and implementation of the Wallingford Package was well coordinated. The package is now well developed and documented and they are extending it to oversea markets.

The third model is CAREDAS, a French model developed by SOGREAH of Grenoble (7). It is well known in Europe partly because of its successful application to the modification of the sewer system in east Paris. For gravity flow in sewers it uses dynamic wave routing which can take care of the downstream as well as the upstream backwaters of the time dependent flow. For surcharged flow it uses the Preissmann slot technique to simulate it as a gravity flow. The model can also handle looped network. It is probably the first model to achieve this condition of simultaneous gravity and surcharged flow simulation. Our ISS Model which was developed slightly earlier is also a full dynamic wave model, but unable to handle surcharged flow nor looped network.

The new EXTRAN block of SWMM is often mistakenly identified as using the Preissmann slot for surcharged flow. In fact, in EXTRAN the surcharged flow is very approximately handled by assuming, among other things, arbitrarily modified junction extending into the pipes appearing like slots. The error due to the assumptions and the explicit numerical solution scheme used doom the practical attractiveness of EXTRAN.

CAREDAS does not have overland surface flow simulation. It is a proprietary model for which detail of the model program is not available.

The fourth model I would like to mention briefly is S-11-S, a Danish model developed by Danish Hydraulic Institute (8). It is now standardized in Denmark and all the Danish companies can use it free, but not for people in other countries. It was built on DHI's System 11 program, specifically modified for sewers. It is also a dynamic wave model with Preissmann slots but it is different from CAREDAS in the sense that they use different solution techniques. Perhaps in its development they were benefited from the experience we learned from our ISS. The S-11-S model has good potential but more testing is desirable. Danish researchers are also developing water quality modeling to go with it.

There is another model that some of you on this side of the ocean might have heard of, and that is the Dorsch Consult HMV Model. It has been mislabelled as a dynamic wave model. It is a simplified diffusion wave model accounting for no downstream backwater effect and I do not intend to go into the detail hydraulics here. There were also other efforts in modeling both storm water quantity and quality and on both overland and sewer flows in Western Europe. Some of these efforts have recently been reported in May 1983 in a special session of the AGU Spring Meeting. Some are reported, e.g., in the proceedings of the Second International Conference on Urban Storm Drainage in 1981 at Urbana.

CLASSIFICATION OF MODELS BASED ON PURPOSES

Before I present my observation on the advantages and disadvantages of storm water modeling on both sides of the Atlantic Ocean, I would like to briefly discuss the classification of the models in order to clarify the different ways of thinking on modeling. There are various ways to class the models. One way is to classify them based on the purposes the models are used for; namely, design, flow evaluation/prediction, and planning. The design models are to design the drainage system itself; i.e., sizing the sewer pipes, and perhaps also the slope and layout of the sewer system.

The flow evaluation/prediction models are to compute the flow in an existing sewer system or a system for which the pipe sizes and slopes are predetermined, for any of the following purposes: (a) for evaluation of adequacy of the system, (b) for real-time operation for the strategy of pollution and/or flood control, and (c) for the design of the storm runoff releasing, treatment, or receiving water body facilities from the storm sewer system. In this country the evaluation/prediction models when used for purpose (c) have often been improperly referred to as the design models. But we should realize in this case the design is not for the sewer system itself but for something else. This unspecified use of the term causes some confusion abroad and in the States as well. Until recently before they learn how "design model" is used by some of us, most Western Europeans think of design models as the models for designing the sewer systems.

The planning models are for the purposes of management planning and decision making for storm water pollution abatement, flood mitigation, and water resources utilization. This group includes models for long range as well as for short term, and for regional or for drainage system specific management planning.

Of course storm water models can be formulated for more than one purpose, and there are such models. For example, the models mentioned previously, SWMM, ILSD, ILLUDAS, TRRL and Wallingford Package can all be used with different accuracies for the design and flow evaluation/prediction of storm drainage system. However, one should be careful that a multipurpose storm water model is not too big and complicated making it inefficient for any one of the intended purposes.

SOME OBSERVATIONS ON EUROPEAN DEVELOPMENT

Now we come to my own observations in view of American practices.

1. National effort

In most of the European countries, storm water modeling is more a national effort. This is perhaps the consequence of the smaller human and financial resources that are available to them in each country.

2. Better coordination "vertically"

They have very good "vertical" coordination from research, testing and verification, technology transfer, to implementation and applications. This good coordination is achieved through good cooperation between the universities and research institutes, the government agencies, and the industry. They are more willing to share.

3. Less coordination "horizontally"

They have less "horizontal" coordination between disciplines. In other words, their cooperation in the storm water quantity and quality aspects is not very good. Denmark is perhaps an exception.

4. Emphasis on water quantity

With exception of Germanic countries, and until recently, they pay much more attention to storm runoff quantity than its quality. Consequently, most of their models deal only with runoff quantity. And they have better practical hydraulic models. We don't have anything hydraulically as good as S-11-S or CAREDAS. In least-cost optimal sewer design models, only ILSD is more versatile and practical than the Wallingford Package. But they are far more inferior in water quality modeling, perhaps to the credit of EPA.

5. Longer range planning

They take a longer range view in their planning, research and development, and marketing.

6. More balanced from research to applications

They pay a more balanced view from basic research to development to testing and verification, to technology transfer, and to implementation. Unlike Americans, they usually provide support for each phase of this development process.

7. More concern on model verification and applicability

Therefore in their data collection they have a longer range plan which very often is a national program, collecting data in view of verification and other requirements. They are more careful on the difference between model calibration and model verification. After formulating a model simulating drainage systems, in calibration of the model to a drainage system the system input and output data are known while the values of the coefficients describing the response or transfer of input to output are determined through calibration. In model verification the input is applied to the model with calibrated values of the model coefficients for the drainage system to produced simulated output which is compared with the measured output. Seldom they would use the same set of data for calibration and verification. And they are more aware of the applicability of the model corresponding only to the range of conditions that were verified.

In conclusion I would say comparatively the American development is more pragmatic and more innovative to solve problems in a short time. We are more advanced in terms of considering storm water quality. In modeling we have more "breadth" but are far less in "depth". This last point is the one that I want to stress because in the long range American companies may end up in a disadvantage position when looking for jobs on urban storm drainage abroad. So we should not just let others look at us. We should also look and learn from the good of others. Perhaps we can see something at the IAHR/IAWPRC Third International Conference on Urban Storm Drainage in June 1984 at Göteborg, Sweden. For those who are interested in model comparison there is a conference on model evaluation using identical sets of data to be held in Yugoslavia in 1985. And finally, if there is anything I can help either within or without the channels of IAHR/IAWPRC Joint Committee or the International Liaison on Urban Storm Drainage I would be most happy to oblige.

ACKNOWLEDGEMENTS

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APPLICATION OF GEO-BASED MODELING TECHNOLOGY FOR STORMWATER MANAGEMENT

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The City of Cincinnati has recently completed a series of projects to define the stormwater problems and feasible management solutions for three neighborhoods within the City. W. E. Gates and Associates (WEG/A) was selected to assist the City on the Projects for two of the areas: the Carthage and Hartwell neighborhoods in the north central-portion of the City.

In completing these projects efforts, WEG/A employed its integrated, geographic information system and modeling technology, called ADAPT (for Areal Design and Planning Tool) to define the character of the existing problems, to specify and test alternative management solutions, and to provide preliminary engineering design and cost estimates for these solutions. The ADAPT system consists of a computerized, spatial (geographic) data base storing any type of mapped information, such as: property boundaries, land use conditions, streets, storm sewers, combined sewers, sanitary sewers, population (projected and existing), and any other features associated with the study areas.

The ADAPT system/data base was interfaced with the existing computerized Street Inventory/record system maintained by the City. This permitted the direct input for information on roadway conditions, culvert conditions, and other street and stormwater related information without requiring any redundant digitizing or data encoding efforts.

In combination with this data base, the ADAPT system includes engineering analysis, design, and costing models/modules necessary to evaluate the characteristics of the stormwater issues in the area. A wide-range of graphic, mapped, and tabular outputs from the data base and/or the models can be obtained to display the characteristics of alternative management strategies for correcting the identificable problems.

For stormwater analyses, the ADAPT models consist of hydrologic models that are capable of: accepting annual rainfall, seasonal, and/or storm event inputs; routing the associated rainfall, (and pollutant characteristics if required) over the digitized landscape stored in the data base and into the associated sewer system infrastructure (also stored in the data base); and comparing the inflow characteristics with the pipe hydraulic capacities (or stream capacities) to determine problem areas and associated flooding/environmental impacts. Design and costing programs are also available to design/simulate alternative management strategies (new storm sewer locations, upstream retention basins, etc.) that are specified by engineers and/or planners to ameliorate the problems identified for the project area. The use of a fully intergrated data base, modeling, and display capability: greatly expanded the number of alternative and its impacts; and provided such outputs much quicker than could have been achieved using manual techniques.

WEG/A worked closely with the City staff to develop the spatial data base and to incorporate local design and costing relationships into the ADAPT models. The output from these project efforts will be utilized in the development of the capital investment program for the Hartwell and Carthage areas for stormwater management activities.

Q-ILLUDAS: A Continuous Urban Runoff/Washoff Model

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Abstract. Q-ILLUDAS is a quasi-continuous urban runoff quantity-quality model. It was developed by the Illinois State Water Survey and is based on their earlier Illinois Urban Drainage Area Simulator (ILLUDAS) model. The model is fully continuous in its accounting of rainfall and soil moisture, but dry period discharges are not modeled.

The rainfall/soil moisture processor accounts for both impervious and pervious depression storage as well as interception by canopy, and utilizes Holtan's infiltration curve for soils of the four basic hydrologic groupings. All storages are assumed to be spatially distributed. Any combination of two rain gages and two soil types may be used to simulate a basin. Discrete accounting is provided for directly connected paved areas, contributing grassed areas, and grassed areas affected by impervious areas which are not directly connected.

The event simulator processes each subcatchment of the user-input branch-reach network in a downstream direction. Backwater conditions, and thus pressure flows, are not considered. If instantaneous input exceeds pipe capacity, the excess is stored at the upstream end until such time as it can be released. Overland flow routing may be done by either of two methods. One method uses a time-invariant concentration time from the most remote point in a subcatchment to its inlet, the other allows a kinematic wave to form on the surface with concentration time based on the mean depth on the overland flow plane. Reach routing is a simple storage routing technique which determines flow through time as a function of inlet peak and full flow discharges.

Urban runoff water quality is simulated as a function of particulate washoff in the basin. A series of work equations determines how much particulate load may be entrained into surface flow each minute, or how much must settle out of the surface flow. The user may specify up to five particle sizes and must provide initial reach loads, accumulation rates, and densities. Constituent concentration for desired pollutants is determined by applying user-specified potency factors for each of the particle size groups simulated. Mechanical reduction of street surface load by street-sweeping may be simulated.

Key Words: Simulation model, hydrologic model, water quality model, particulate loads, street sweeping

Introduction

Urban stormwater runoff and the associated dissolved and suspended washoff loads have become a focal point of both government and local studies over the past decade. During the course of investigating this non-point source pollution problem, several area-wide plans were developed around the United States which incorporated either street-sweeping at various frequencies or the construction of settling basins, or both. The idea behind street sweeping is to attack the problem at its source by depleting the available surface load, while the idea of the settling basin is to reduce the suspended load after it has left the street surface.

During the early stages of the Section 208 planning process, the project managers and staff at the various participating agencies were faced with the task of determining the benefits to water quality attainable by these management practices. Because of the scarcity of pertinent literature and the misinterpretation that the efficiency of the street sweeping in removal of street dirt is directly proportional to its efficiency at removal of particular constituents in runoff, a great deal of variance was found among the different agencies as to the effectiveness of these programs.

At this point, the U.S. Environmental Protection Agency decided that before hundreds of millions of dollars were spent in persuance of these plans, more pertinent data should be collected as to the effects of these management strategies on urban receiving stream water quality.

The ensuing federally sponsored program, the Nationwide Urban Runoff Program (NURP), was intended to meet this need by both identifying the non-point source problems and by investigating the effects of various urban "best management" practices on local and receiving stream quality.

The development and use of water quality simulation models has closely paralleled this evolution of federal programs. Before federal and local government agencies became more interested in urban and agricultural water quality, most practicing engineers and planners were satisfied to estimate the rainfall-runoff relationship by the "rational formula", and to approximate water quality utilizing general empirical formulas or simple mathematical models. In 1966, Linsley and Crawford[1] showed that with the help of the high-speed digital computer the individual components of the hydrologic cycle could be reasonably approximated to generate a "real-time" rainfall-runoff relationship rather than relying on a black box approach as before.

A long list of simulation models has followed, some of which are capable of modeling water quality. The water quality algorithms of these models, which were available during the 208 program, were based on the exponential washoff equation. The 208 program made clear the need for a model based on the removal of surface particulates. The Non-Point Source (NPS)[2] model was used to a limited degree during the 208 planning, but had been designed to model agricultural areas and lumped the particulates into one group. The Particulate Transport Model[3] was not generally available in time to be used, but did address the problem of particulate removal by particle size.

The need was recognized at the Illinois State Water Survey for a continuous urban model that would be capable of modeling water quality as a function of particulate removal from the street surface while being inexpensive to use, very straightforward in data requirements and calibration, and non-proprietary. Q-ILLUDAS is the result of this endeavor.

BACKGROUND

The State Water Survey has been actively involved in urban hydrologic simulation since 1974 when ILLUDAS[4], a single event hydrologic model, was released. ILLUDAS has become one of the most popular urban hydrologic models available over the last ten years. The model's world-wide use is attributable to its inexpensive execution costs, its small storage requirements, its well-tested empirical relationships, and the user service provided by ISWS.

Because of the large number of users already familiar with ILLUDAS, it was decided that a continuous model based on many of the existing algorithms and input data from the model would make the new model attractive to current ILLUDAS users. In its original design, Q-ILLUDAS was to be the continuous version of ILLUDAS and QUAL-ILLUDAS[5], an exponential washoff based model. The NURP program, however, eliminated the ties between the new model's water quality algorithms and those of QUAL-ILLUDAS by electing to model water quality as a function of the physical processes involved in removing particulates on the urban streets and lawns. The new model is composed of two major processors: one is the rainfall/soil moisture processor which models the processes involved with increases and decreases in soil moisture and impervious depression storage; the other is essentially a modified version of ILLUDAS that processes the effective hyetographs for each event on the user-defined basin to produce hydrographs and pollutographs.

PLAN OF REPORT

Part 1 of the report presents the theory behind the development of the new model, Q-ILLUDAS, and addresses the major changes, when applicable, with respect to the predecessor model, ILLUDAS. Part 2 of the report discusses the verification of the model's hydrologic simulation, while Part 3 discusses verification of the water quality algorithms.

The goal of this study has been to develop an objective and reliable method by which urban storm runoff and washoff can be analyzed both for the design and evaluation of urban drainage systems.

part 1. theory and development

The two most dominant features of the new model with respect to its predecessor models are the continuous nature of the rainfall/runoff processing and the replacement of the exponential washoff equation with a series of algorithms that model water quality as a function of the overland flow's ability to remove particulate loads. The model hierarchy has been designed in such a way as to provide the most efficient analysis of both events and intervening dry periods as possible. After initialization of the model run, the program executes along the paths shown in Figure 1.

During dry periods the model operates on three different time steps: daily if there is no rain fall on the current day; hourly if there is no rainfall during the current hour, but there is rainfall at some time during the day; and at the event level, which may be one, two, three, four, five, six, ten, twelve, fifteen, twenty, or thirty minutes, if there is rainfall during the hour. Storage gains due to infiltration from depression storage, and storage losses due to percolation and evapotranspiration are modeled during these periods.

When rainfall is encountered, the program enters the rainfall processor algorithm which generates increases to the abstraction storages and also generates a series of effective hyetographs for each raingage-soil type combination asked for. After the event rainfall has been processed, the appropriate set of effective hyetographs is applied to each reach in the system. If water quality is not being simulated, the time of concentration is computed and the effective hyetographs are converted to overland flow hydrographs. These hydrographs are then added to the outlet hydrograph from the upstream reach, if any, and routed through the current reach.

When water quality is being modeled, the preceding dry period is simulated by accumulating surface load as prescribed by the input data, and performing street sweeping if required. Surface runoff is then simulated by the kinematic wave algorithm to provide instantaneous overland flow velocities. These velocities are used to determine the average work potential of the storm water during the interval, and to determine the entrainment potential for the interval. The resulting inlet hydrograph and suspended load time series are then routed through the reach. If constituent loads or pollutographs are desired for the reach, user supplied partitions are applied to generate the necessary output. At the end of the simulation, the dry period accumulation algorithm is entered again to provide final load information. The individual elements of the new model algorithms and supporting definitions will now be discussed.

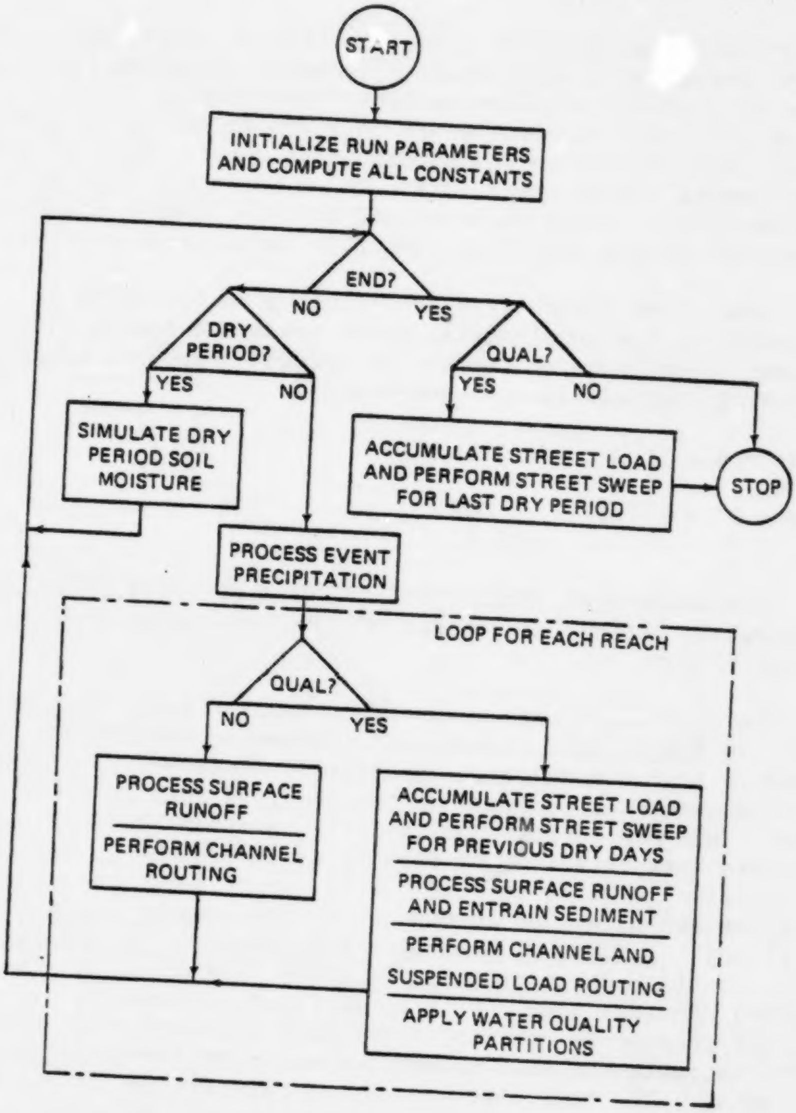

START
INITIALIZE RUN PARAMETERS AND COMPUTE ALL CONSTANTS
END?
NO
YES
DRY PERIOD?
YES
NO
SIMULATE DRY PERIOD SOIL MOISTURE
QUAL?
YES
NO
ACCUMULATE STREEET LOAD AND PERFORM STREET SWEEP FOR LAST DRY PERIOD
STOP
PROCESS EVENT PRECIPITATION
LOOP FOR EACH REACH
QUAL?
NO
YES
PROCESS SURFACE RUNOFF
PERFORM CHANNEL ROUTING
ACCUMULATE STREET LOAD AND PERFORM STREET SWEEP FOR PREVIOUS DRY DAYS
PROCESS SURFACE RUNOFF AND ENTRAIN SEDIMENT
PERFORM CHANNEL AND SUSPENDED LOAD ROUTING
APPLY WATER QUALITY PARTITIONS

Figure 1. Flow diagram for Q-ILLUDAS

LAND COVER TYPE DESCRIPTIONS

Q-ILLUDAS accepts the identification of three basic land surface cover types for a subcatchment: directly connected paved areas (CPA), such as roadways and parking lots; contributing grassed areas (CGA), which are those pervious areas that are deemed to be significant in their contribution to the subcatchment runoff, such as front yards; and supplemental paved areas (SPA), which are areas such as sidewalks and residential rooftops whose runoff does not have a completely impervious flow path to the inlet but must flow across some pervious area.

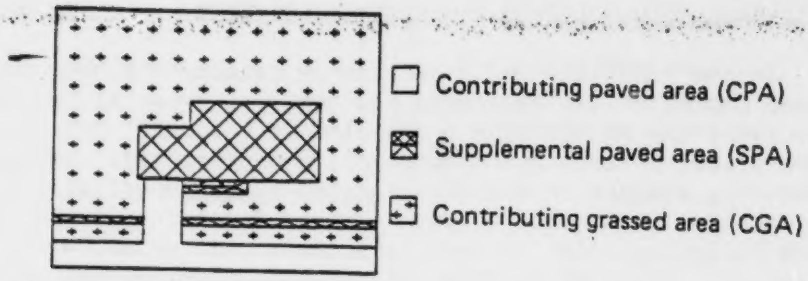
These three cover types are illustrated in Figure 2a. In ILLUDAS, rainfall on the supplemental paved areas was simply distributed by linear weighting over the entire grassed area, therefore making the incoming rainfall for grassed areas:

$$R' = R \cdot (1.0 + SPA/CGA) \tag{1}$$

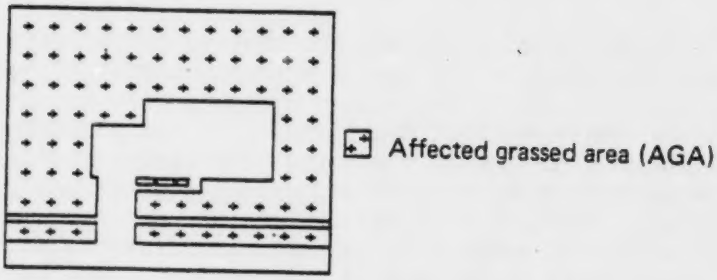
where R' = rainfall on CGA
R = actual rainfall

This assumption (Figure 2b) has been modified in Q-ILLUDAS to more accurately define those areas affected by runoff from supplemental paved areas (Figure 2c).

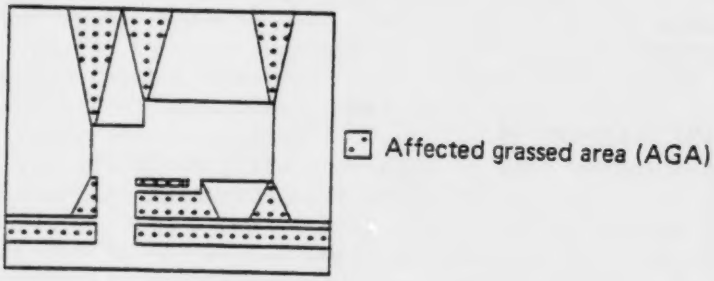
The same three land cover types as previously discussed are used by the new model; but, rather than processing SPA and CGA as one surface type, a fourth cover type, processed independently of CGA, is generated to represent that portion of the pervious area affected by runoff from SPA. This new surface/soil profile is referred to as the affected grassed area (AGA). This area is assumed to be at most twice the size of SPA, and will be less if CGA is not at least twice as large as SPA. The acreage under CGA is reduced by the acreage assigned to AGA. The previous treatment of SPA/CGA misrepresented the grassed area runoff to the extent that the rooftop, driveway, and sidewalk runoff affected the entire pervious area. This simplification tends to overestimate the runoff from areas not really affected by runoff from SPA, and underestimate the soil saturation and runoff from areas which were affected. The new method processes rainfall on SPA for impervious depression storage, and then uniformly distributes the resulting hyetograph over the AGA, along with the rainfall falling directly on AGA, which has been abstracted for interception storage of the canopy. From this point on, runoff is processed for two pervious surface covers, CGA and AGA.


Contributing paved area (CPA)
Supplemental paved area (SPA)
Contributing grassed area (CGA)

(a) GENERAL SURFACE COVER DEFINITION


Affected grassed area (AGA)

(b) PREVIOUS TREATMENT OF SPA BY ILLUDAS


Affected grassed area (AGA)

(c) NEW TREATMENT OF SPA BY Q-ILLUDAS

Figure 2. Treatment of supplemental paved areas

a) General surface cover definition

b) Treatment of SPA by ILLUDAS

c) Treatment of SPA by Q-ILLUDAS

RAINFALL/SOIL MOISTURE PROCESSING HIERARCHY

In the simulation of a particular catchment's hydrology, any combination of two raingages and two soil types may be used. In order to avoid the repetitious processing of rainfall, the new model pre-processes each hydrologic soil group/raingage combination before deciding whether or not the expected basin runoff will exceed the user-supplied minimum volume required for routing. During dry periods, the following order is used to process soil moisture and surface water storage: evaporation from interception storage; evaporation and infiltration from depression storage; evapotranspiration and deep percolation from soil moisture storage. All of these processes incorporate the spatial distribution described below. Wet periods are processed following the same hierarchy as above. On impervious surfaces, depression storage is the only abstraction considered.

All of the above processes are assumed to be spatially distributed, and are simulated by the use of a triangular distribution. Figure 3a shows that the distribution is assumed to vary linearly from zero to twice the user-specified mean value over the subcatchment area. DEPG, as an example, is the mean pervious depression storage. Figure 3b shows the concurrent processing of depression storage and infiltration potential. Although both the filling of depression storage and infiltration are assumed to be spatially distributed as in Figure 3a, they are assumed to be totally independent of one another physically. Depression storage may therefore be considered to have a uniform distribution with respect to infiltration potential.

As shown in Figure 4a, there are four basic state variables required to define the current status of any process or storage: MAX, which is two times the mean value; NX1, the current storage curve intercept; NX2, the current maximum depth in storage; and STO, which is the current total volume in storage. S represents the moisture supply depth in the current minute. Figure 4b shows the change in the values of parameters NX1, NX2, and STO as a result of this moisture supply. E represents the excess moisture supply. The processing of losses may be illustrated using Figure 4a. If we allow S to represent the evapotranspiration potential during the minute, the volume of STO below S is assumed to satisfy part of the potential and the values of NX1 and NX2 are lowered by S. The volume below S and to the left of the storage curve NX1 at the start of the minute is unsatisfied potential and is passed on to the next process in the hierarchy.

The concurrent processing of infiltration and depression storage, Figures 5a and 5b, assumes that infiltration potential, varying from zero to 2FINC, is satisfied for a particular level of supply, S, before considering depression storage. The supply rate is the sum of the rainfall after interception losses and the uniformly distributed volume of depression storage at the start of the interval. This assumption allows for infiltration from both depression storage and from surface storage. The volume below S and between the curves 2FINC and MAX

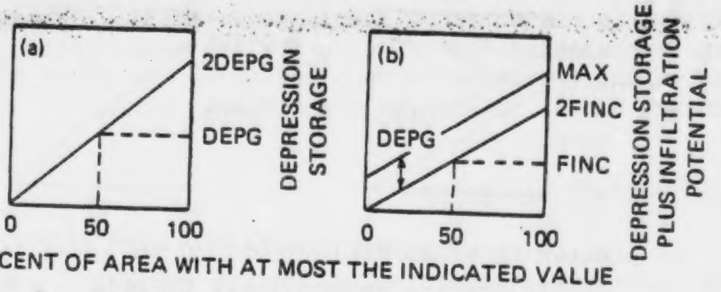

(a)
2DEPG
DEPG
DEPRESSION STORAGE
0
50
100
(b)
MAX
2FINC
DEPG
FINC
DEPRESSION STORAGE PLUS INFILTRATION POTENTIAL
0
50
100
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 3. Spatial distribution definitions

a) Basic distribution

b) Concurrent depression storage and infiltration potential

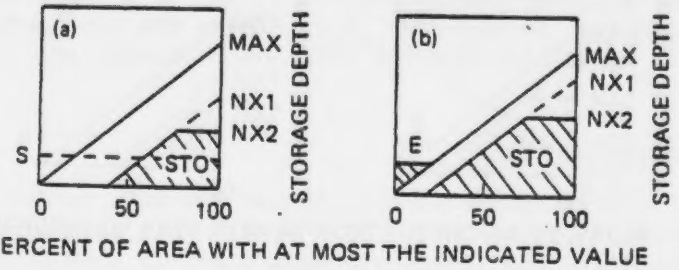

(a)
MAX
NX1
NX2
S
STO
STORAGE DEPTH
0
50
100
(b)
MAX
NX1
NX2
E
STO
STORAGE DEPTH
0
50
100
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 4. Storage gain using spatial distribution

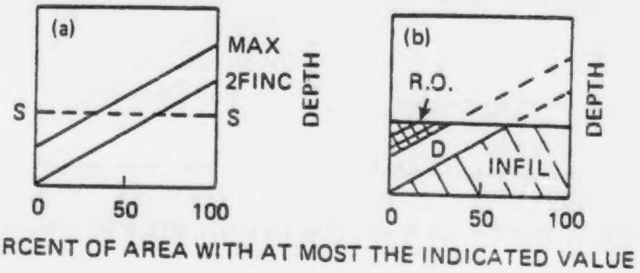

(a)
MAX
2FINC
S
S
DEPTH
0
50
100
(b)
R.O.
D
INFIL
DEPTH
0
50
100
PERCENT OF AREA WITH AT MOST THE INDICATED VALUE

Figure 5. Concurrent processing of moisture supply

a) Start of interval

b) End of interval

represents the moisture supply to depression storage in the interval, D, and is processed according to the above discussion of Figures 4a and 4b. The volume remaining below S and above the curve bounded by MAX is the surface runoff volume for the minute.

LAND SURFACE PROCESSES

The processing of surface runoff by the model is undertaken only if the approximate runoff volume of the event will exceed a user-defined minimum value. The surface runoff for a particular subcatchment is generated utilizing the pre-processed effective hyetographs along with the physical parameters of the area. It is assumed that all front yard runoff will be routed overland to the street and be uniformly distributed along the roadway's length. Backyard runoff may also be routed to and over the street, or it may be assumed to run off directly to a drain via the back lot line. There are two surface routing methods available in Q-ILLUDAS which will now be discussed.

Time Area Distribution

This is the method which is used by ILLUDAS, for both impervious and pervious areas, with one major change. This is a linear convolution method in which the time of concentration is used to determine isochrones, or, in other words, to develop a contour map of the catchment whose intervals are time to inlet in minutes. The algorithm uniformly distributes the tributary area about the longest flow path, and aggregates the outfall hydrograph as shown in Figure 6. The only change made in this algorithm is the use of the kinematic wave equation to compute the concentration time for all surfaces. The kinematic wave equation is:

$$tc = 0.94 \cdot (L \cdot n/ S)^{0.6} / i^{0.4} \tag{2}$$

where tc is the time of concentration, in minutes; L is the overland flow length, in feet; n is Manning's roughness; S is the surface slope, in ft/ft; and i = moisture supply rate, in in/hr.

Kinematic Wave Generator

Although the above method generates acceptable results from the stand point of runoff volume, runoff timing, and overall hydrograph shape, close inspection reveals that the peak time tends to lag a bit, and radical changes in the slope of the hydrograph tail are common. These factors are the result of assuming a constant velocity for surface runoff throughout the event. This causes slower than observed response at high discharge rates, and faster than observed responses at the relatively low rates. An attempt has been made to remove these biases

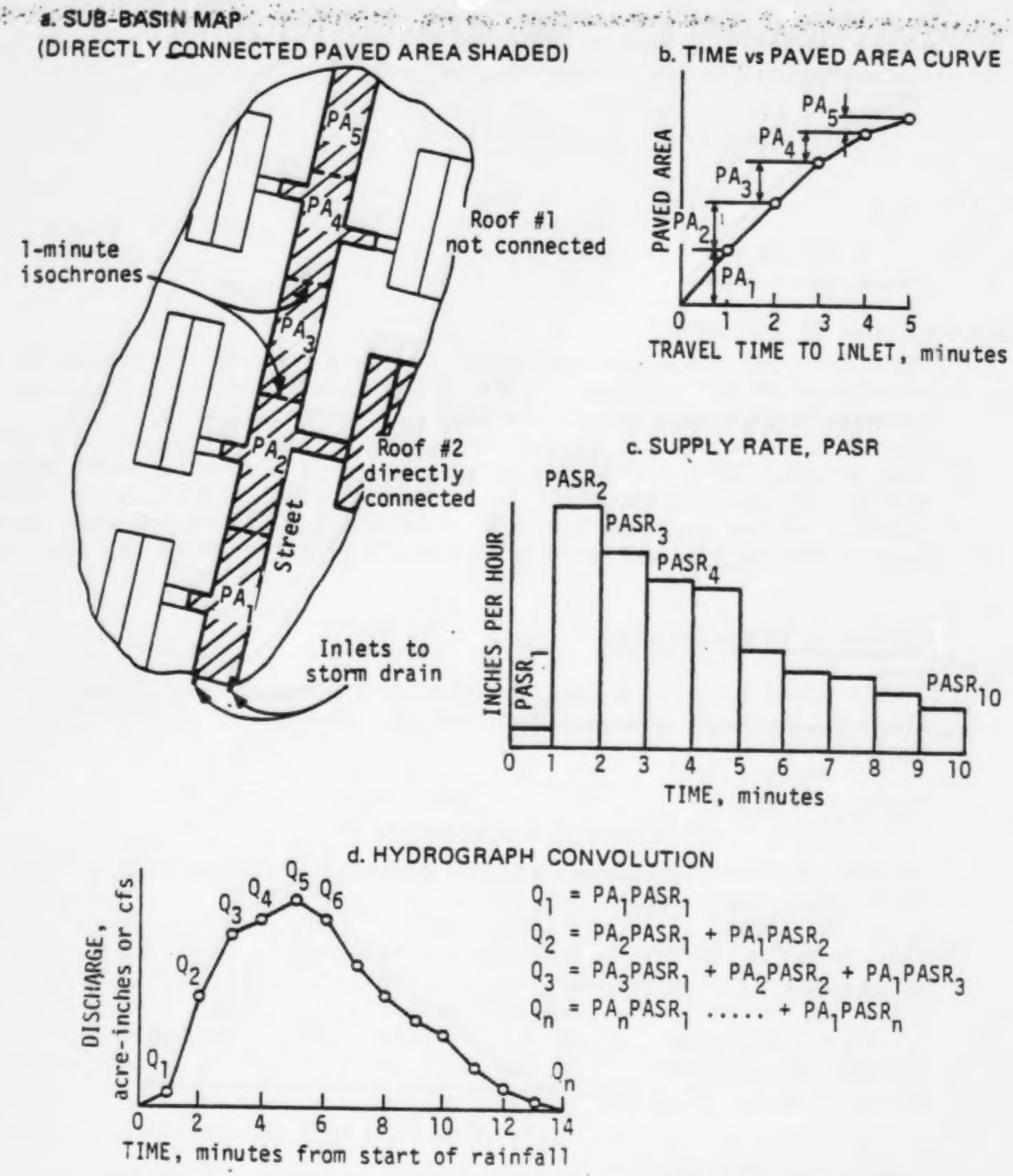

a. SUB-BASIN MAP
(DIRECTLY CONNECTED PAVED AREA SHADED)
PA_5
PA_4
Roof #1
not connected
1-minute
isochrones
PA_3
PA_2
Roof #2
directly
connected
Street
PA_1
Inlets to
storm drain
b. TIME vs PAVED AREA CURVE
PAVED AREA
PA_5
PA_4
PA_3
PA_2
PA_1
0
1
2
3
4
5
TRAVEL TIME TO INLET, minutes
c. SUPPLY RATE, PASR
INCHES PER HOUR
$PASR_1$
$PASR_2$
$PASR_3$
$PASR_4$
$PASR_{10}$
0
1
2
3
4
5
6
7
8
9
10
TIME, minutes
d. HYDROGRAPH CONVOLUTION
DISCHARGE, acre-inches or cfs
Q_1
Q_2
Q_3
Q_4
Q_5
Q_6
Q_n
0
2
4
6
8
10
12
14
TIME, minutes from start of rainfall
$Q_1 = PA_1PASR_1$
$Q_2 = PA_2PASR_1 + PA_1PASR_2$
$Q_3 = PA_3PASR_1 + PA_2PASR_2 + PA_1PASR_3$
$Q_n = PA_nPASR_1 \; ..... + PA_1PASR_n$

Figure 6. Elements in the development of the paved area hydrograph by the time-area method

a) Sub-basin map (CPA shaded)

b) Time vs. paved area curve

c) Supply rate (PASR)

d) Hydrograph

by allowing a modified kinematic wave to develop on the surface. This method, shown in Figure 7, computes the value of tc_i, the time of concentration for the i^{th} minute, as

$$tc = 0.94 \cdot (L \cdot n/ S)^{0.6} / \left[(I_i /2) + \frac{1}{L} \sum_{j=1}^{N} (\Delta x_{j,i-1}) d_{j,i-1}\right]^{0.4} \tag{3}$$

where I_i is the effective hyetograph ordinate for the i^{th} minute, N is the number of differential depths on the flow plane, $d_{j,i-1}$ is the average depth at the end of the last minute for sector j of the kinematic wave, and $\Delta x_{j,i-1}$ is the length of sector j at the end of the last minute. By allowing tc_i to vary based on both the current surface storage and the current input to surface storage, the surface runoff velocity varies with increasing or decreasing depth on the flow plane, thus improving the simulated hydrograph's correlation to the observed.

Surface Load Accumulation

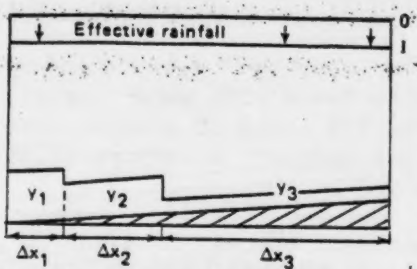
When water quality is being simulated, the model determines the elapsed time since the last event ended. The linear accumulation function,

$$PLOAD_{j,n} = PLOAD_{j,n-1} \cdot (1-r_j) + DEP_j \cdot (K) \tag{4}$$

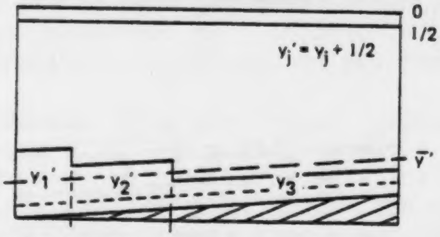
is then utilized to approximate the accumulation of street dirt in each of the five size groups, designated by subscript j. In the above equation, $PLOAD_{j,n}$ is the surface load of particles in group j at time t=n, in kg; r_j is the natural removal rate due to wind, decay, etc., in kg lost per kg load per day; DEP_j is the accumulation rate for group j, in kg per day per curb-kilometer; and K is the number of curb-kilometers in the subcatchment. If street sweeping is being simulated, the model reduces the surface load in each size group according to user specified sweeper removal efficiencies.

Surface Load Removal

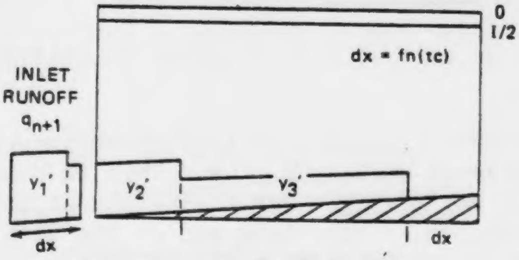
The concept of modeling water quality as a function of surface sediment load removal is not an original concept. The NPS model utlizes sediment removal and applicable constituent partitions to generate pollutant loads.[2] The NPS model, however, looks only at gross sediment removal utlizing the exponential washoff equation. With the NPS model, washoff pollutographs generated from the sediment load will differ linearly as a function of the partitioning factors.


Effective rainfall
0
I
y_1
y_2
y_3
Δx_1
Δx_2
Δx_3

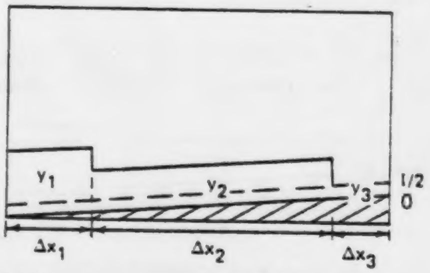
(a) Differential depth of storage and rainfall for time = t_n


0
I/2
$y_j' = y_j + I/2$
$\bar{y}'$
y_1'
y_2'
y_3'

(b) Differential storage plus mean rainfall over current interval, I/2


0
I/2
dx = fn(tc)
INLET
RUNOFF
q_{n+1}
y_1'
y_2'
y_3'
dx
dx

(c) Determine runoff to inlet for interval from time of concentration where tc = fn($\bar{y}'$)


y_1
y_2
y_3
I/2
0
Δx_1
Δx_2
Δx_3

(d) Modified Kinematic wave at end of interval, time = t_{n+1}

Figure 7. Modified kinematic wave surface routing

The PTM model also deals with water quality as a function of surface sediment removal, but looks at various size groups within the load. The PTM model utilizes sediment transport equations to determine the sediment removal.

Q-ILLUDAS' sediment removal is based on a series of work equations derived from literature published by Allen and Garde[6,7], and draws on the work of Sutherland. The surface routing and entrainment algorithms[8] approach sediment removal on a micro-scale, with a spatial convolution technique being employed to accumulate basin inlet hydrograph and loadographs from the characteristic hydrograph and loadographs generated by the following techniques.

The water quality algorithms used in Q-ILLUDAS require the use of the kinematic wave surface routing option in order to have variable surface runoff velocities. The model will use this method whether the user has requested it or not during water quality simulation. A typical reach in an urban catchment may have several curb inlets; therefore, it is not practical to model the paved surface runoff as one lumped hydrograph. The model takes a user-specified "characteristic" lane length and width and the number of inlets in the subcatchment to generate a characteristic surface runoff hydrograph and the associated surface washoff loadographs. The convolution of these characteristic time series to a set of spatially distributed inlet time series will be discussed later.

The movement of particles into and out of suspension is done by balancing a series of work equations. This is done simply by equating the potential of the moving water to the sum of the work it is exerting to move the current suspended load and to the work required to entrain and move a fraction of the remaining bed load. If the runoff velocity lessens to the point where the current suspended load requires more work than is available, the program allows a portion of the suspended load to settle back to the surface.

Before particles of a particular size group, j, may be entrained to the suspended load, the average boundary shear stress, τ_o, of the flow, given as

$$\tau_o = y(\rho_f) g \sin \alpha \qquad (5)$$

must exceed the critical tractive shear stress, τc_j, for the size group,

$$\tau c_j = \frac{6}{\pi} \cdot D_j \cdot (\rho_j - \rho_f) \cdot g \cdot \cos \alpha \cdot (\tan \phi_j - \tan\alpha) \qquad (6)$$

where y is the depth over flow plane, ρ_f is the density of water, g is the gravitational acceleration, α is the bed slope, D_j is the mean diameter of particles in group j, ρ_j is the density of particles in group j, and ϕ_j is representative of the packing of particles in the bed load for group j. If $\tau_o > \tau c_j$, then the gross work potential of the fluid is determined as

$$POT_n = \tau o_n \cdot A_n \cdot V_n \cdot dt \qquad (7)$$

where POT_n is the gross work potential of the fluid for the nth minute, A_n is the wetted surface area under the flow, V_n is the surface runoff velocity for time n, and dt is the time interval in seconds. The work currently being done by the fluid to keep particles of group j in the suspended state, $WRKLD_{j,n}$, is defined as

$$WRKLD_{j,n} = SUS_{j,n} \cdot (V_n \cdot dt + Y_n/2) \cdot g/WRKEFF_j \qquad (8)$$

where $SUS_{j,n}$ is the total current suspended load of group j at time n, and $WRKEFF_j$ is the efficiency coefficient for the fluids ability to entrain and transport sediment from group j. When equation 8 is summed for the five groups and subtracted from POT_n the determination of settling or entrainment may be made.

When the difference is positive, entrainment may occur if the average boundary shear is greater than the critical tractive shear for a particular group. There are two limitations on the amount of sediment being entrained, one being the mass which would exactly balance the work equation, $WRKLIM_j$ and the other being the availability of particles from group j on the flow surface, $BLOAD_j$. The determination of the first limit requires the determination of the work that would be required to entrain the entire remaining surface load in group j, which is

$$WRK_{j,n} = PLOAD_{j,n} \cdot (V_n \cdot dt + Y_n/2) \cdot g/WRKEFF_j \qquad (9)$$

in which $WRK_{j,n}$ is the total work required.

The limiting value then becomes

$$WRKLIM_j = PLOAD_{j,n} \cdot [MIN \{1, (POT_n - \sum_{j=1}^{5} WRKLD_j) / WRK_j\}] \qquad (10)$$

The physical availability of particles of a particular size group is a function of the original load and the current load for the event. This limitation is known as "bed armoring", or the pining of some particles beneath particles of significantly larger size. A simple bed-armoring equation used by Alley et al.[3] is

$$BLOAD_{j,n} = PLOAD_{j,n} \cdot Zn \cdot (1 - PLOAD_{j,n} / PLOAD_{j,0}) \qquad (11)$$

where Z_n is the fraction of the flow plane wetted during the nth interval. The actual surface load being entrained for the interval is the minimum of $BLOAD_{j,n}$ and $WRKLIM_{j,n}$.

If the net available potential, $POT_n - WRKLD_{j,n}$ is negative, then settling of particles occurs until a zero net is achieved. The settling function weights decrease in suspended load for each group as a function of Stoke's Law of Settling, which states

$$Vs_j = \frac{1}{18} (\rho_j - \rho_f) \; g \; D_j^2 \; / \; \mu \tag{12}$$

where Vs_j is the mean settling velocity for particles of group j, and μ is the viscosity of the fluid.

CHANNEL PROCESSES

The channel processes are governed by one card of parameters per reach. The drainage network is identified by a branch-reach designation system through which the program may keep track of the connectivity of the system. Point sources may now be input for up to twenty-five constituents using daily average discharge rates and daily mean concentrations of modeled constituents. Q-ILLUDAS, as did its predecessor, allows a desired storage volume to be requested for a reach, which results in the generation of a maximum discharge required to generate this volume of storage. The model also accepts a maximum outflow parameter for a reach. If specified, the model will indicate what minimum volume of storage is required to provide this upper limit. This same parameter, when given a negative value, generates a discharge sink, that is, all discharge up to the absolute value of this parameter is removed from the basin, such as might happen if a combined sewer interceptor intersects an urban catchment. In the case of stored volumes of water, the program assumes that complete mixing of the suspended load takes place while in storage.

Testing of the implicit routing technique relative to the simple storage routing technique showed that the more time-consuming implicit method really provided no significant improvement over the simple time shifting algorithm, so the implicit method was dropped. The time shift method simply computes the minimum flow-through time for the reach, and determines a shifting factor, NSHIFT, equal to the flow-through time divided by the routing interval. The various time series for the reach are then shifted NSHIFT intervals in time. The routed hydrographs and loadographs are then stored in two vectors which allow up to seven branches to be open at any one time.

Because characteristic lengths are used to model surface runoff on paved areas, it is necessary to input the resultant inlet hydrographs and loadographs to the reach in a spatially distributed manner. This is done by a method of "backward" or "upstream" convolution which is a function of the inlet locations and the estimated flow-through time of the reach. The estimated flow-through time is a function of the peak of the upstream hydrograph, if any, and two times the local characteristic hydrograph peak. This process generates an upstream hydrograph which, when routed through the reach, will account for the location of inlets along the primary flow path.

POLLUTOGRAPH GENERATION

The generation of a pollutograph for a particular constituent is accomplished by applying a potency factor for each size group to the ordinates of the appropriate loadograph, and summing for each size group. Thus,

$$C_{i,n} = \sum_{j=1}^{5} L_{j,n} \cdot (P_{j,i}) / (K \cdot Q_n) \qquad (13)$$

where $C_{i,n}$ is the concentration of pollutant i at time n, $L_{j,n}$ is the loadograph ordinate for group j at time n, $P_{j,i}$ is the potency factor in grams of constituent i per gram of sediment group j, Q_n is the discharge during interval n, and K is a conversion factor to produce units of mg/l. An example of this partitioning process may be seen in Figure 8.

part 2. verification of hydrology

This segment of the paper will deal specifically with the performance of Q-ILLUDAS as a hydrologic model. On the following pages a series of comparisons of observed versus simulated hydrographs from a single model run are used to illustrate the accuracy of the new model in terms of rainfall-runoff modeling. It should be noted that due to time constraints and project commitments, the authors have yet to test the model on basins outside the Champaign-Urbana area.

Rainfall-runoff simulations of two of the four major study basins for the NURP project in Champaign will be used to illustrate the hydrology results attainable with the model. Figures 9 through 14 show the observed and simulated hydrographs for the John Street basins. The observed data was collected by a computer operated telemetry system. The simulated hydrographs are the result of model runs for the period of March through November 1980, utilizing the one-minute precipitation records collected by the telemetry system. These two basins are low density residential basins. John South comprises an area of 39.2 acres, and John North comprises 54.4 acres. The model does a very good job of simulating the basin flows throughout the nine month run, in terms of peak discharge, peak time, and overall hydrograph shape. It should be pointed out that the John South basin has a hydraulic problem just upstream of our sampling point. The model surcharges at about 5 cfs, as does the actual basin, illustrated by the points of inflection on both the rising and falling limbs of the July 27 observed hydrograph. The observed peak does, however, go higher than 5 cfs due to pressure flows

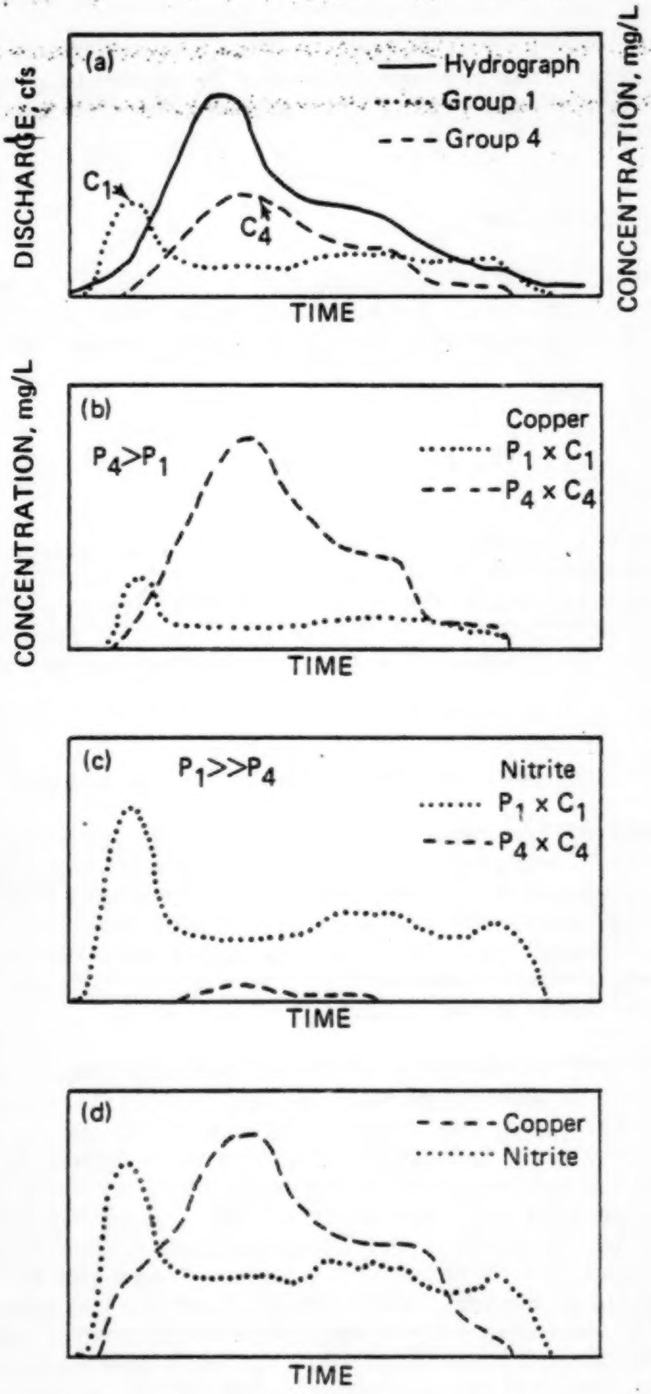


Figure 8. Constituent partitioning in Q-ILLUDAS

a) Event hydrograph and laodographs for groups 1 and 4
b) Multiplication of loadographs by copper potency factors
c) Multiplication of loadographs by nitrite potency factors
d) Copper and nitrite pollutographs generated by summing curves in (b) and (c), respectively

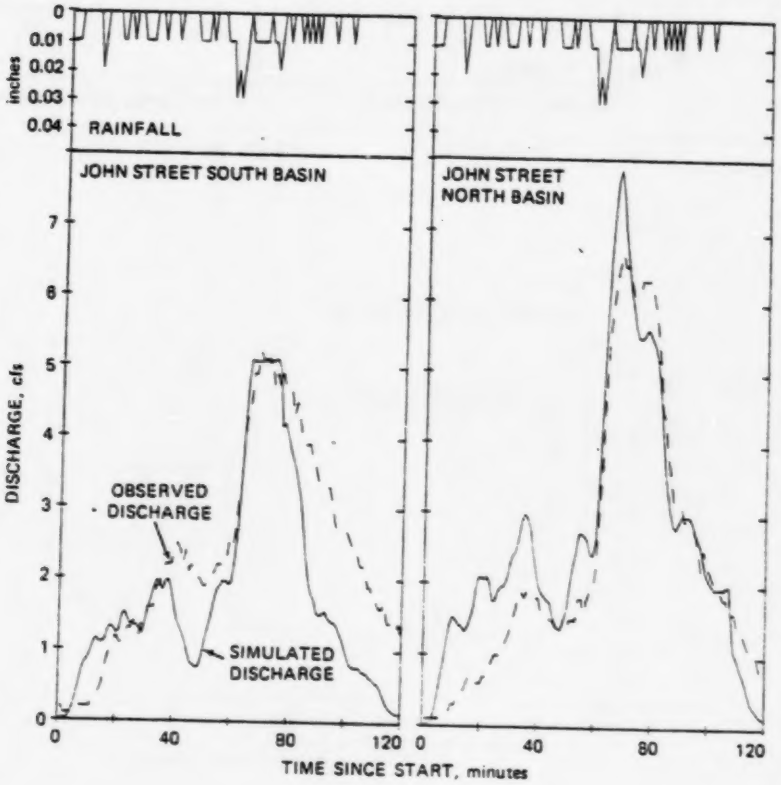


Figure 9. Simulated and observed hydrographs for event of March 16, 1980

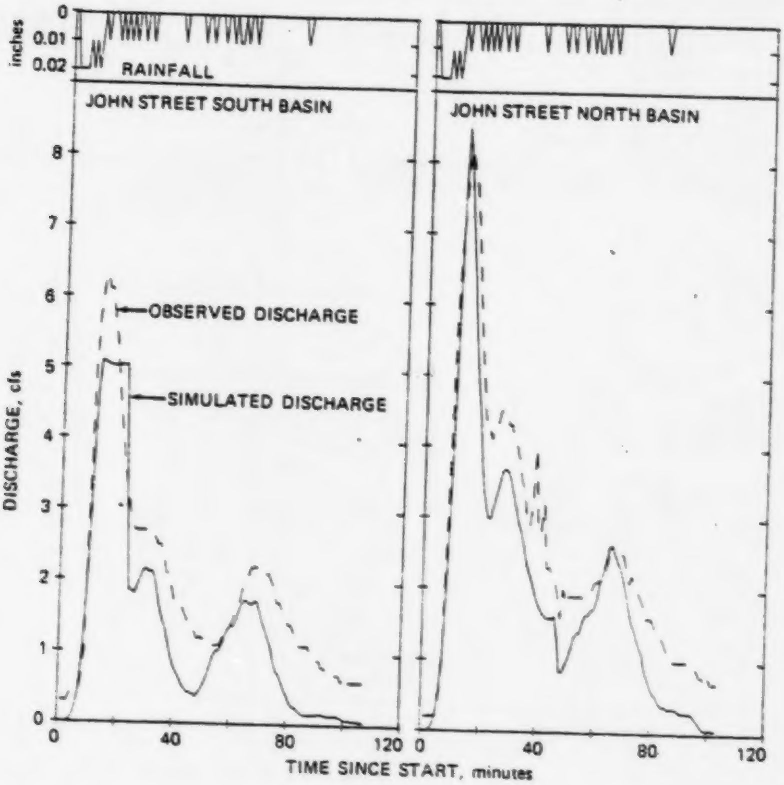


Figure 10. Simulated and observed hydrographs for event of May 17, 1980

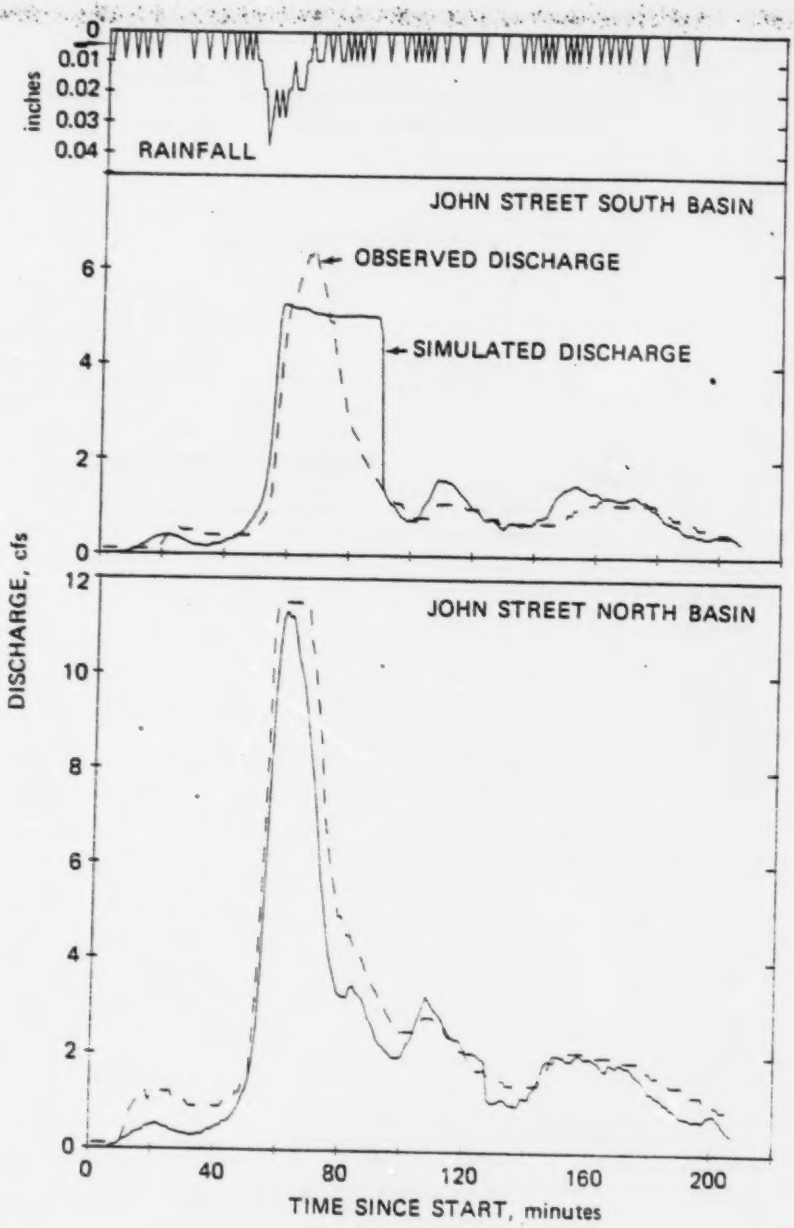


Figure 11. Simulated and observed hydrographs for event of July 27, 1980

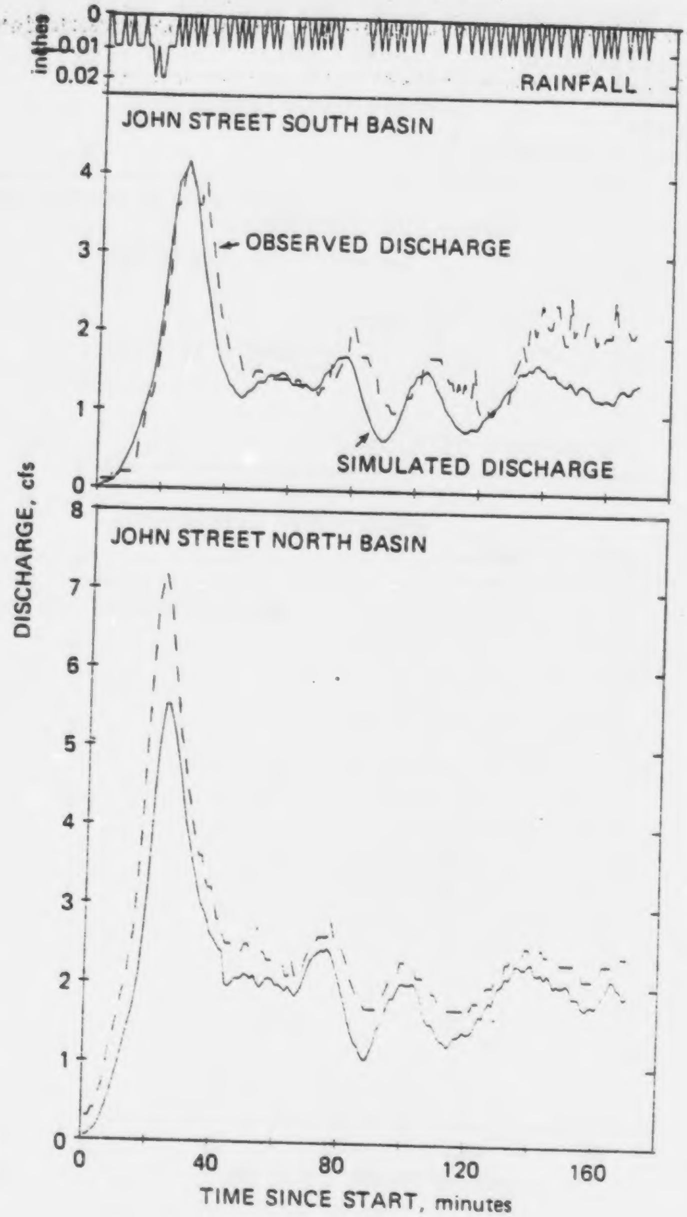


Figure 12. Simulated and observed hydrographs for event of September 16, 1980 .

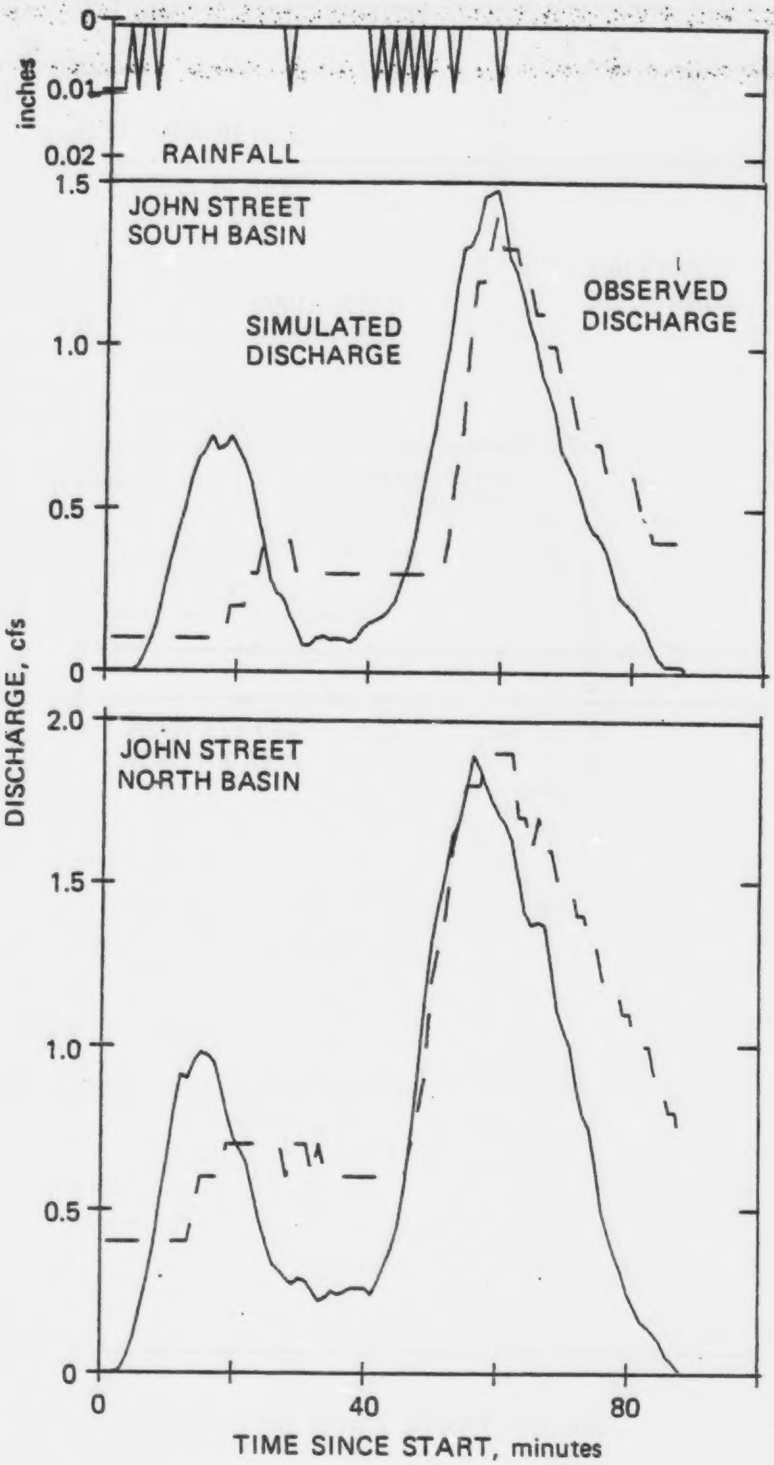


Figure 13. Simulated and observed hydrographs for event of October 1, 1980

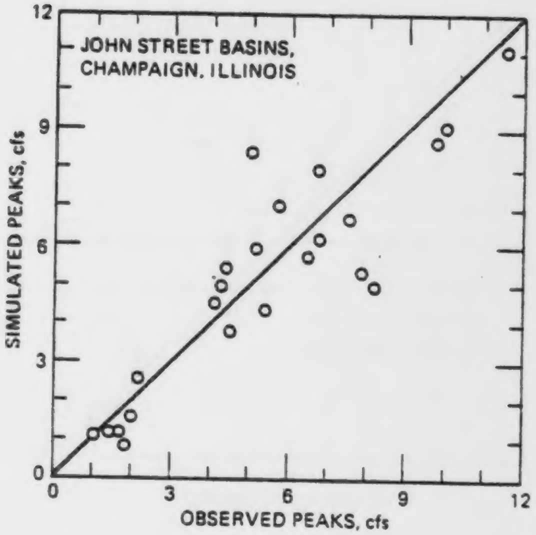


Figure 14. Simulated and observed event peak discharges for 1980

caused by several feet of head. The October 1 event shows that the model also does a respectable job on events of relatively small magnitude. Figure 14 shows a scatter diagram for simulated versus observed peak discharges seen on the basins.

part 3. verification of water quality

The John Street South Bain is comprised of thirty-nine acres of single family housing with a relatively moderate volume of traffic. The results shown on the following pages were generated by simulating the accumulation and washoff of five sediment size groups. These five groups were represented as having effective mean diameters of 8, 30, 95, 185, and 600 microns. Potency factors for six constituents were estimated by linear regression, and fine tuned by trial and error.

Figure 15 shows the observed and simulated discharge for an event on March 16, 1980, followed by simulated pollutographs and observed data points for all six modeled constituents. The irregularity of the pollutograph curves is a function of the accumulation of five grossly different loadographs.

In all cases except for phosphorus; the shape, timing, and concentrations of the simulated pollutographs fit the same trends of the observed data quite well. The undersimulation of phosphorus at the start of the event is probably due to our choice to correlate the appearance of phosphorus in washoff to the medium sediment sizes in washoff although it has been shown that phosphorus in urban runoff correlates with larger particles early in the event, and smaller sizes later.

Figure 16 represents the simulation of the June 28, 1980, storm event. In this case, the choice of phosphorus potency factors yields results much more consistent with the observed data.

Figure 17 shows the simulation of solids washoff for the event of July 27, 1980. In comparison to the simulated hydrograph of Figure 12 for this event, one notices the improvement in simulated hydrograph shape generated by the local hydrograph and loadograph convolution algorithm referred to in the section on channel processes in Part 2. This algorithm is not utilized unless water quality is being simulated.

Figure 18 again shows the simulation of phosphorus and Kjeldahl-nitrogen for an event of August 18, 1980. Again, the observed phosphorus data points (open circles) confirm the decision made as to a strong correlation between the expected appearance of phosphorus and medium sized particles (185 microns).

Figure 19 shows scatter diagrams of simulated (vertical) versus observed (horizontal) event mean concentrations for the six constituents.

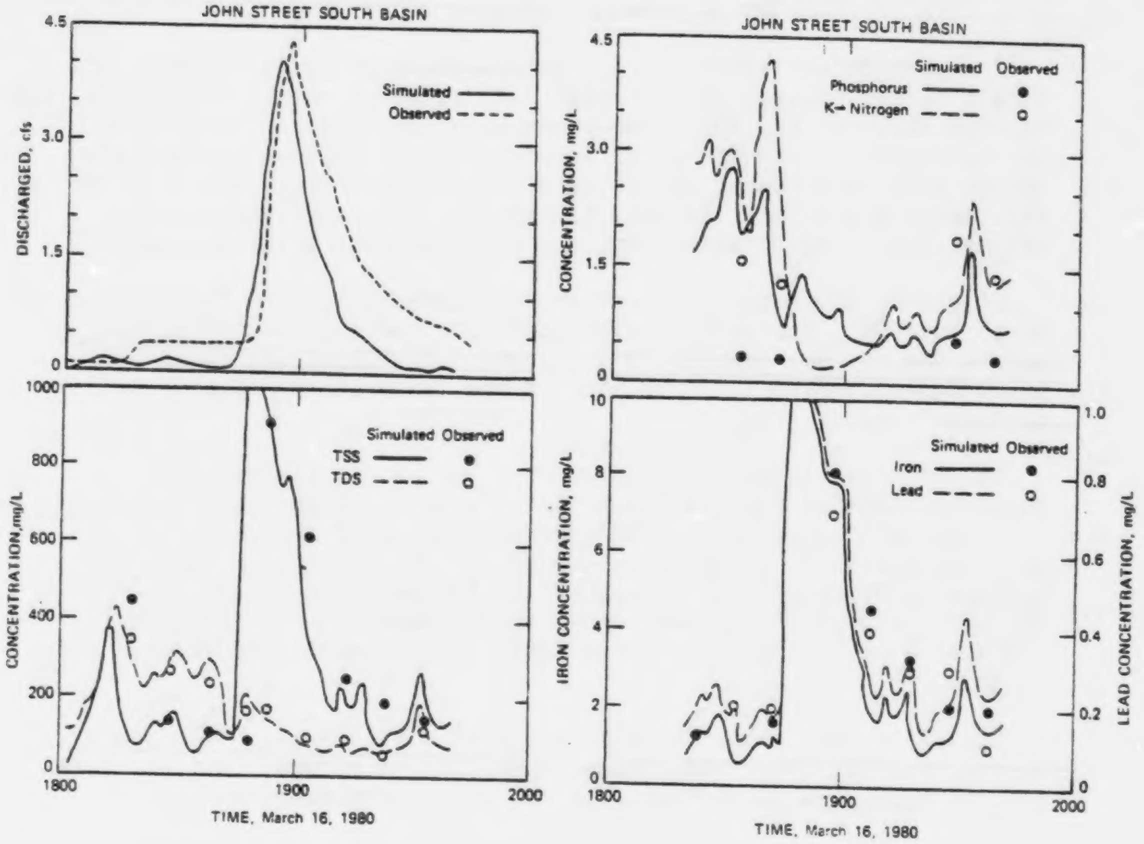


Figure 15. Water quality simulation for March 16, 1980

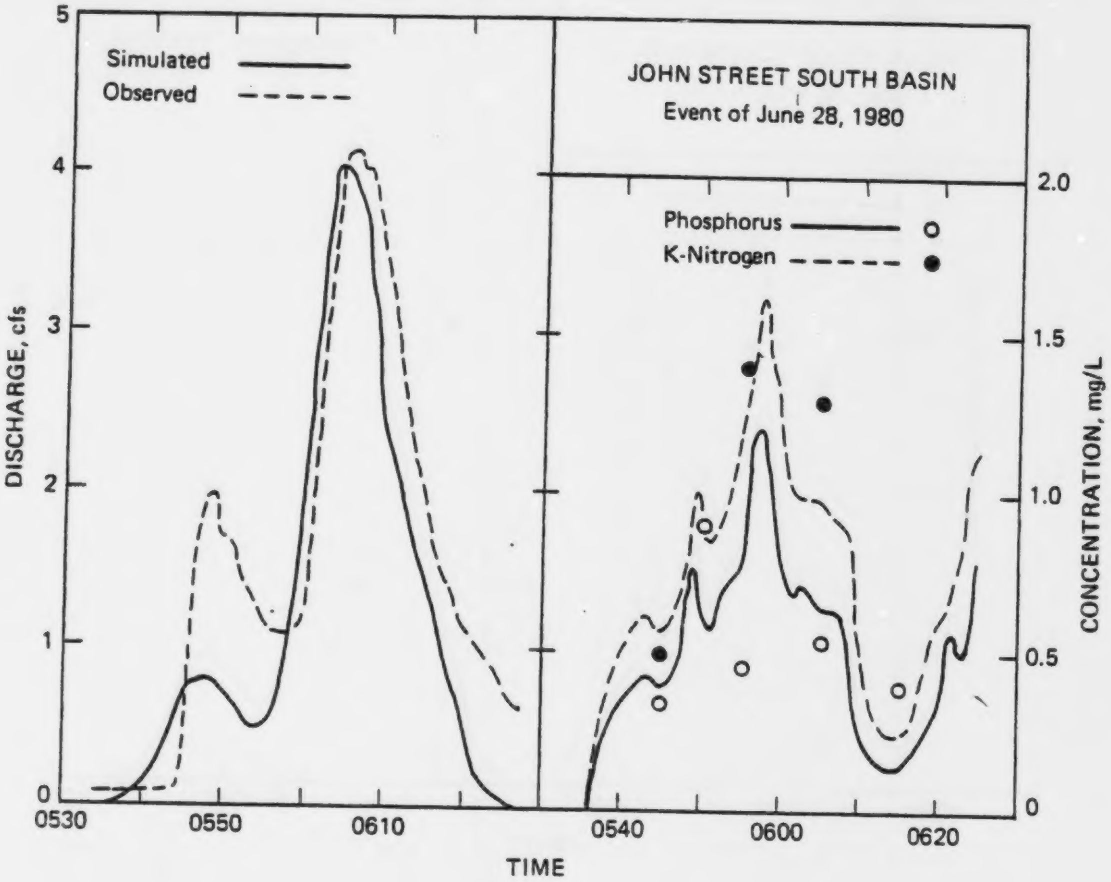


Figure 16. Water quality simulation for June 28, 1980

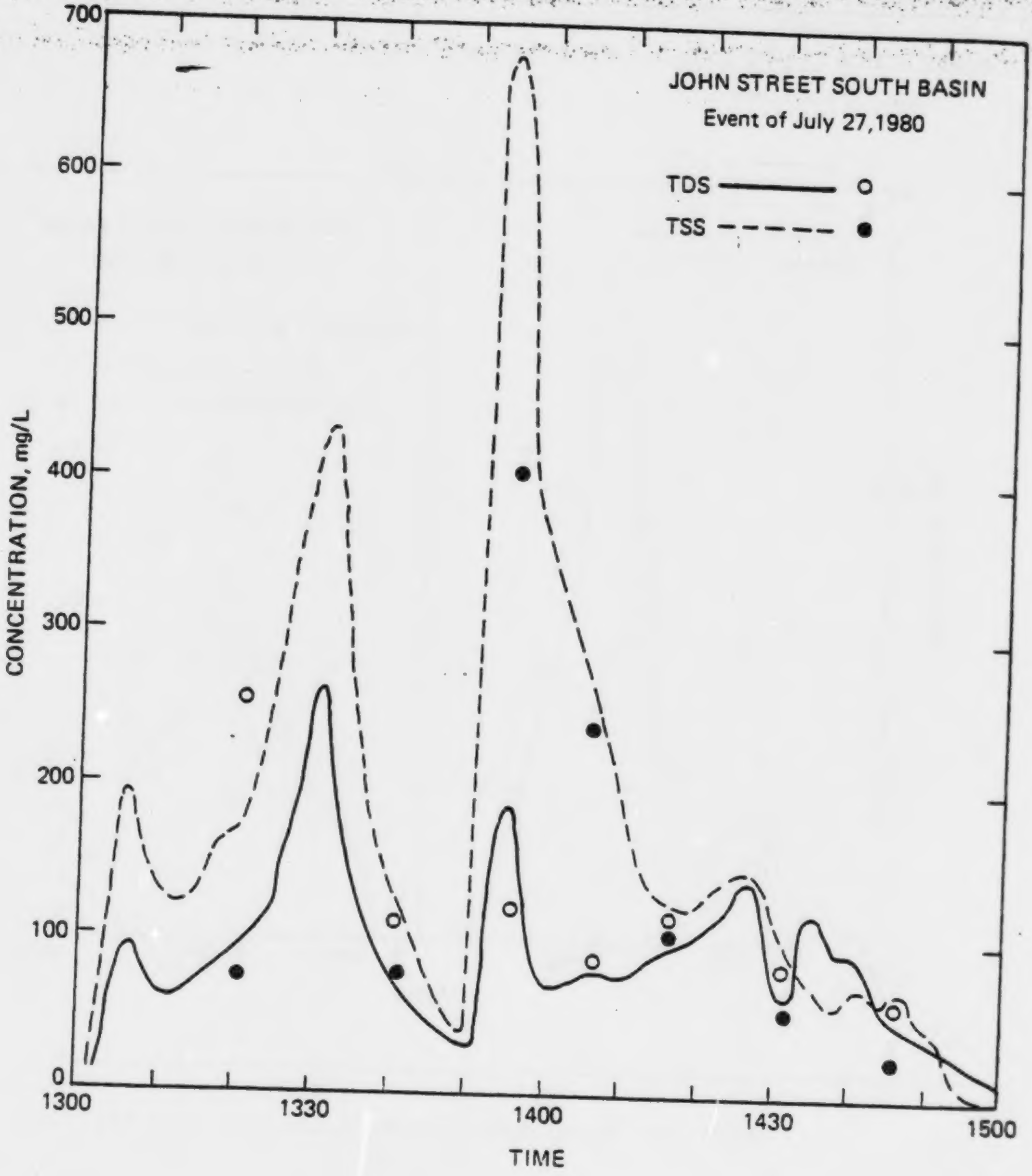


Figure 17. Water quality simulation for July 27, 1980

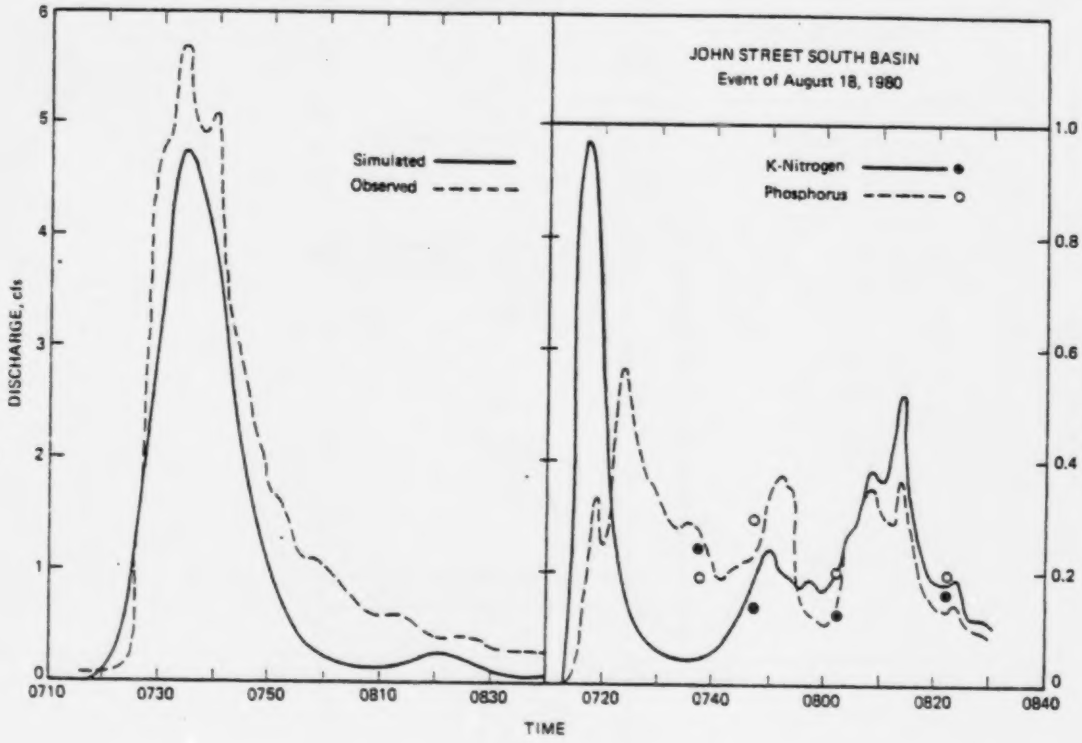


Figure 18. Water quality simulation for August 18, 1980

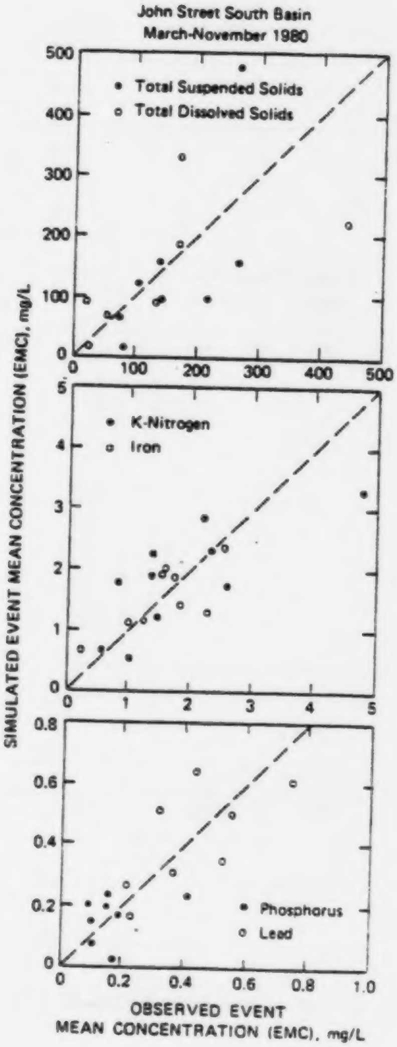


Figure 19. Simulated vs. observed event mean concentrations

In conclusion, we feel that the new sediment-based water quaity algorithms in Q-ILLUDAS do a good job of representing the constituent concentrations in urban runoff.

conclusions

In summary, the authors feel that the model's ability to simulate urban storm runoff is very good. This evaluation is based on the model's simulation of hydrograph peaks, shape, and peak timing. The accuracy of the hydrologic model is considered to be the result of its basic incorporation of the ILLUDAS model, and the changes described in this paper which are regarded as being more representative of the physical processes affecting urban runoff than its predecessor model.

The authors' evaluation of the water quality simulation capability of the model is that it falls between satisfactory and good. The authors' understanding of both the trends in the observed and simulated pollutographs and in the model's algorithms tend to lend themselves to a "good" rating. It is felt however that a curve-fitting technique that would allow partial entrainment from the particle size group just larger than those meeting the entrainment criteria would produce a smoother simulated pollutograph and would result in enhancing the overall confidence in the water quality simulation.

In conclusion, it is felt that the new model can be a valuable tool in both the hydrologic evaluation of existing urban stormwater drainage systems and in the design of new drainage networks. It is also felt that the water quality simulation capabilities of the model can be similarly valuable with some refinement.

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THE OUTLOOK FOR FUTURE FLOODING IN ILLINOIS

By

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Illinois State Water Survey

INTRODUCTION

A growing impression among those who deal with floods in urban areas is that flooding is on the increase. A typical question we often receive is, "Why did we have two 50-year storms during the last year?"

Severe flooding last December occurred in Illinois because of two weather events. Illinois had heavy November rainfall with record highs of 6 inches in northeastern Illinois. Then on December 2-3, Illinois had a record heavy 1-day rainfall for Winter. A band of 4 to 5 inches of rain extended from St. Louis to Chicago. Unfortunately it was centered along the Illinois River Basin and affected several communities.

- Was this freak? Yes, it was on all time record 1-day rain for December.

- Are there more of these events now than in prior years? The answer is yes!

The trends in flooding and climate in Illinois, with specific references to urban areas, are the focus of this paper. For many obvious reasons, it is easy to predict that flooding will increase.

First, the growth of urban areas has and will continue to produce increased flooding. Urbanization of rural landscapes, in general, generates bigger and faster flood peak flows from a given rainstorm. A 6-inch rainstorm in DuPage County today produces a different and higher flood-peak than the same storm did 50 years ago. These flood flows also expand the area of the floodplains, especially those small ones for which no streamflow history is available, and over which suburban expansion has often extended. Age-related loss of effectiveness of water control structures, and decay of older urban drainage systems, add to the present and future increase in both flood severity and flood frequency. Society will likely choose to continue to expand its occupancy of flood-prone lands, another factor in the unfortunate but correct prediction of increased future flooding in urbanized areas.

However, I want to focus on another factor, one that many either don't yet realize, or adequately appreciate. Changing climate will continue to increase urban and rural flooding to a greater degree than all of man's urban land use shifts activities. There is a significant on-going change in climate, and particularly in large metropolitan areas.

I want to explore the effect of the on-going climate change in flooding and initially I will address the state scale. Changes across the state basically reflect natural atmospheric conditions without any measurable influence of man. In the second part of the paper I focus on the local changes of rainfall in the major urban areas of Chicago and St. Louis where man's influence on the weather has added another dimension to increased rainfall and more flooding.

TRENDS IN FLOODS AND RELATED CLIMATE CONDITIONS IN ILLINOIS

Introduction

The summer rainfall values for Illinois show a trend to wetter conditions in the late 1960's and 1970's. Winters in the last 20 years have also become much colder and somewhat wetter than in the prior 50 years, suggesting a higher potential for snow melt floods. The degree of variability around the trend is critical, and it has gotten greater in the last 10 years. An important water resources and management question is whether these recent fluctuations in climate have been sufficient to affect the number or intensity of floods.

A study of streamflow and relevant climate variables was pursued to address this question. The period of 1921-1980 was selected and 11 basins with long records were studied.

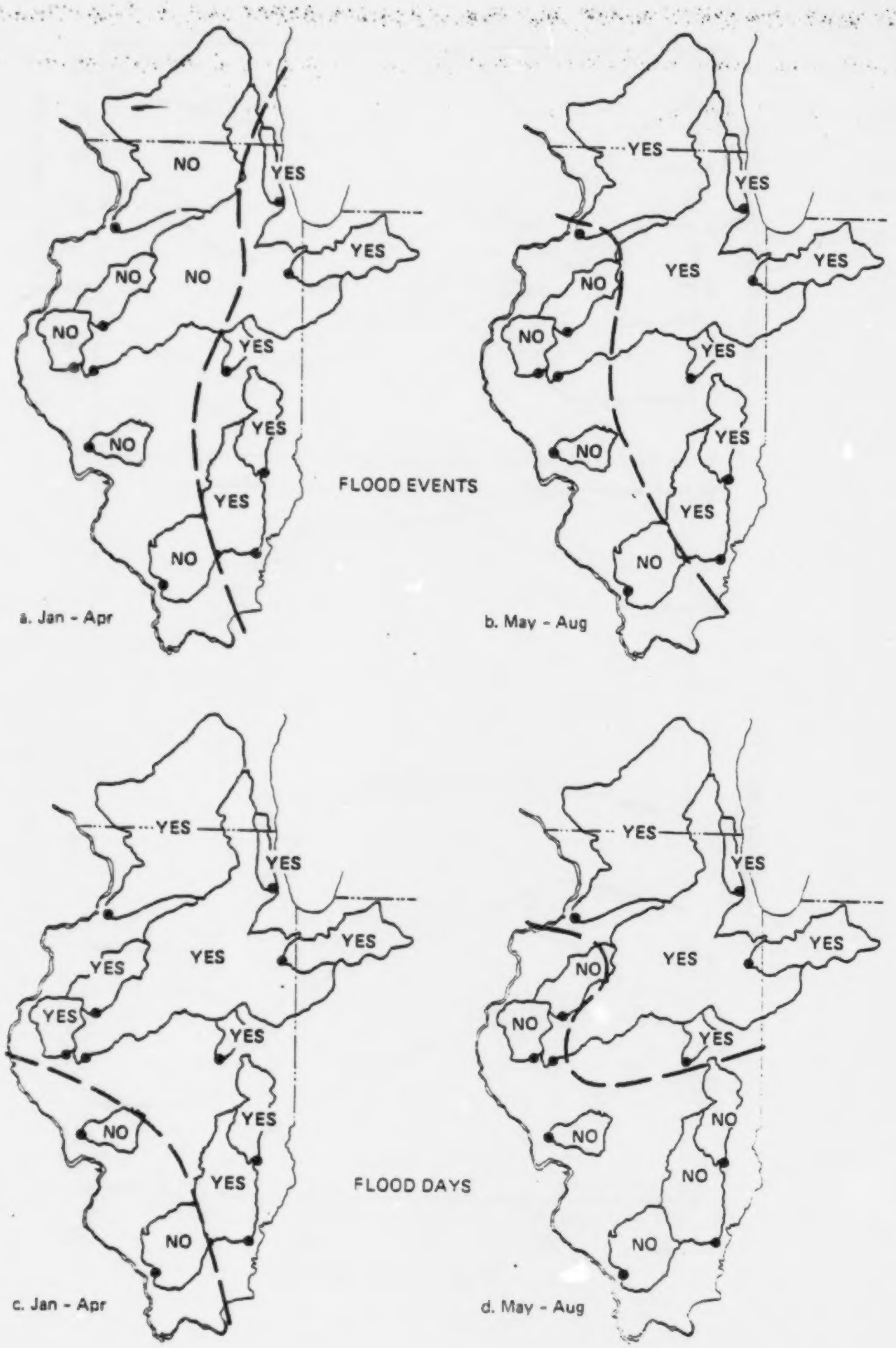
The shift from rural land uses to urban usage could be relevant since the shift to more impervious surfaces leads to greater flooding. The percent of Illinois in rural or non-urban land uses, in 1921 was 90%, and by 1980 this percentage had changed to 81%. Thus, a 9% increase in lands in urban usage occurred over 60 years. This increase, although sizable, is not as great as those noted in flooding events or in flood durations.

Trends in Floods

Winter. For the winter (Jan.-Apr.) flood frequencies (events), we found five basins with up trends, and 6 had no trends, up or down (Fig. 1). The durations of winter floods showed marked up trends in 9 basins. Figure 1 shows the areal distribution of basins with uptrends (a "yes" on the map) of winter flood durations. The statewide values, based on all 11 basins, showed a 67% increase in winter flood durations since 1921, and a 43% increase in number of floods. Has the climate changed enough to cause these?

The decadal average values of winter precipitation and temperature for 4 locales embracing the state appear in Figure 2. Three of the precipitation values had up trends, and the two most significant ones (Aurora and Urbana) were where the greatest increases in winter floods occurred. Statewide, the winter precipitation has increased by 8% from 1921 to 1980. The winter temperature values reveal a marked decrease and one that is statewide, with an average decreases of 3°F, representing a 20% decrease.

Winter flood durations increased most where winter precipitation has increased the most; that is, in the north and central sections. Study of



FLOOD EVENTS

a. Jan - Apr

b. May - Aug

FLOOD DAYS

c. Jan - Apr

d. May - Aug

NO
YES
YES
NO
NO
NO
YES
NO
YES
YES
NO
YES
YES
YES
YES
NO
NO
YES
YES
NO
YES
NO
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YES
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Figure 1. Presence of statistically significant up trends in flooding (events and days) from 1921 to 1980. Yes indicates a trend; no indicates no trend.

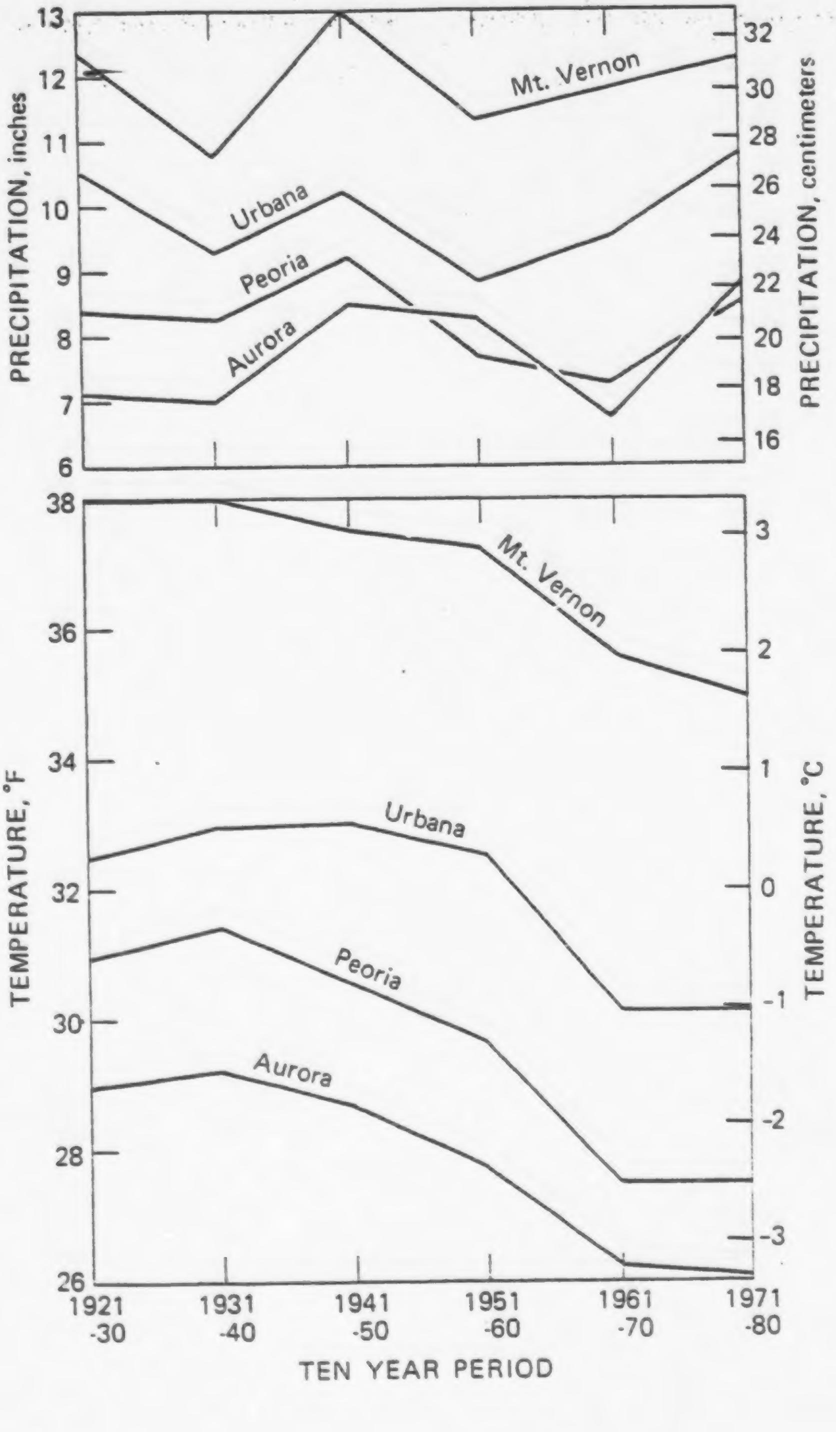


Figure 2. Values for each decade (1921-80) of winter (Dec-Mar) precipitation and temperatures.

Table 1. Five-Year Statistics on 2-Inch Storms and Overflows at Chicago.

5-Year	Number of ≥ 2-Inch Storms	Number of Overflows	Percent $\left(\frac{\text{number of overflows}}{\text{number of storms}}\right)$
1948-51	19	3	16
1952-56	21	2	10
1957-61	25	4	16
1962-66	14	3	21
1967-71	16	3	18
1972-76	18	6	33
1977-81	26	13	50

the annual maximum river stages due to ice jams on the Des Plaines and Rock Rivers show only 4 were due to ice jams in the 40 years from 1921 to 1960, but 10 were due to ice jams in the past 20 years (1961-80). Thus, the colder temperatures are having an influence, particularly in the northern half of Illinois, by increased river ice.

Summer. Floods have also increased in summer (May-August) when floods are due to heavy rainstorms. Seven of the basins had definite upward trends in summer floods from 1921 through 1980, denoted by "yes" on Figure 1. The basins with more summer floods are in the eastern 3/4's of Illinois. Figure 3 shows the flood frequency graphs, based on decade values, for two basins in NE Illinois (one urban, one rural). Both exhibit distinct up trends in their summer and winter frequencies to 1971-80 maximums. Flood durations for these basins also show winter and summer increases.

The incidence of heavy rains during summer was studied because shifts in the number of these events should produce shifts in summer floods. The presence of upward trends in heavy rain events appears in Figure 4. Crop districts with upward trends, reaching a maximum in the 1971-80 period, occurred in the eastern half of Illinois. This areal distribution agrees closely with patterns of increased summer flood events, as shown in Figure 1.

The statewide values of heavy rains, shown in Figure 5 show a general up trend. The number in 1921-30 was 112 days per summer, increasing to 143 heavy rain days in the 70's. The difference of 31 days is a 27% increase. Also shown is the statewide number of floods. These increased from 31 in 1921-30 to 56 in 1971-80. This increase of 25 floods in 60 years represents an 80% change. Land use changes, rural to urban, which represented a 9% change upwards, also are a partial influence in this upward trend in floods.

Other evidence of the impact of more heavy rains on floods is shown in Table 1. This shows the frequency of overflows from Chicago drainage system back into Lake Michigan. These are a result of heavy rain events. Note that the two highest numbers of overflows have occurred in the two most recent periods.

Our statewide basin studies strongly suggest that the numbers of floods and their durations both have exhibited a major increase across most of Illinois during the past 60 years. Much of the increase has been in the last 20 years, reaching a maximum during the 1971-80 decade. The statewide increase in flood conditions is related to:

a) an increase in the number of heavy rain days in the May-August period; and

b) an increase in winter precipitation and a corresponding decrease in winter temperatures which also occurred over this 60-year period.

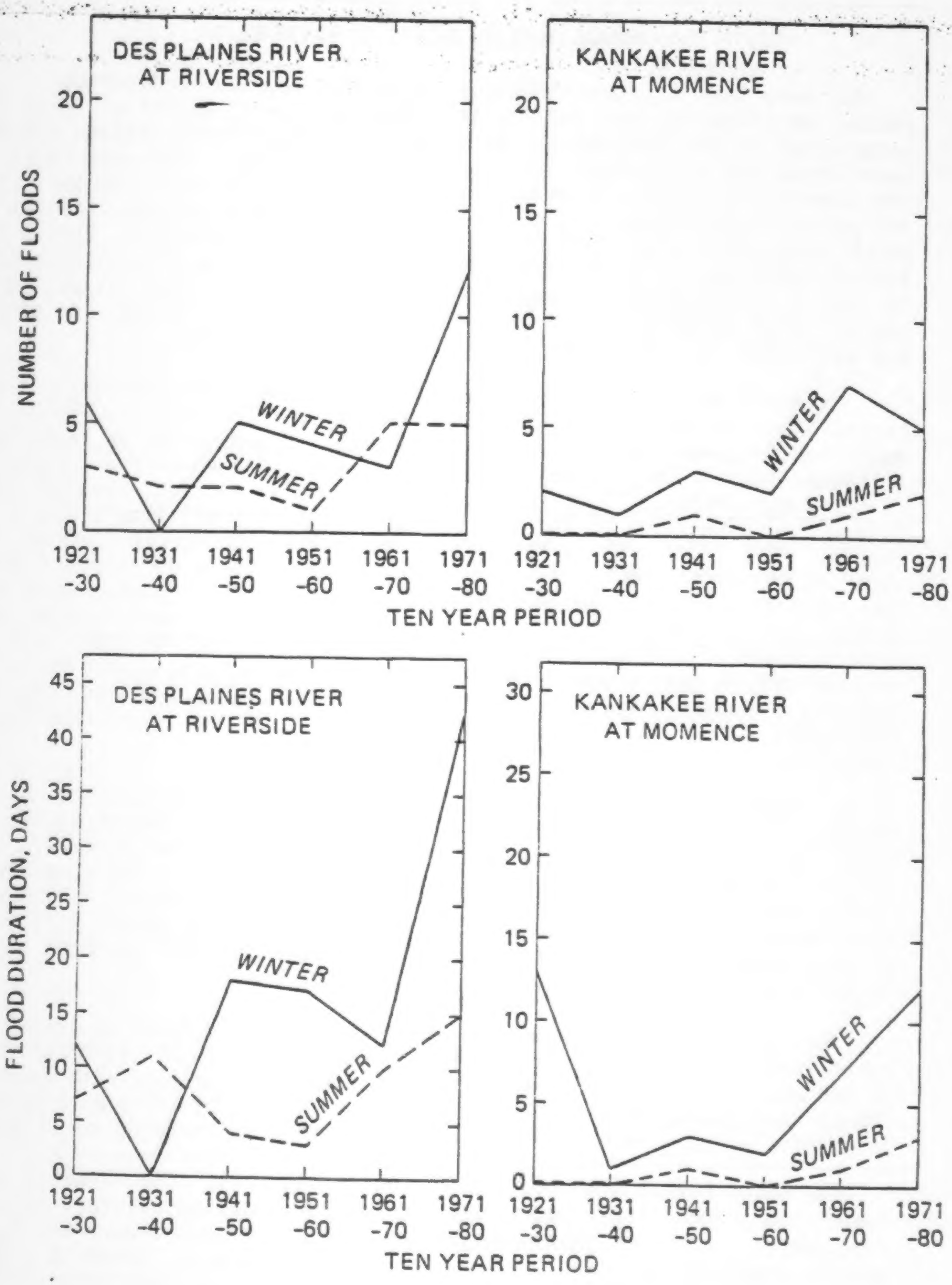


Figure 3. Graphs of summer and winter numbers and durations of floods on the Des Plaines and Kankakee Rivers, 1921-80.

URBAN-INDUCED SHIFTS IN RAINFALL

For more than 20 years the Water Survey has studied inadvertent weather modification, and particularly that due to influences of large urban areas on the atmosphere. We intensively studied the Chicago and St. Louis areas and have established that rainfall changes, particularly in the summer, are sizable in and beyond these areas as a result of the influences of the urban area on the atmosphere. There are four factors by which large urban areas influence the atmosphere and rainfall. These include added particles to form raindrops; added heating which causes air to rise and to condense moisture to help make clouds; mechanical mixing of the air which produces convergent and increased convection over the city; and additional moisture from certain industrial processes.

Figure 6 depicts the average area of increased summer rainfall at St. Louis. Note the area where heavy, short-duration (1 to 6 hours) rain rates are increased by 50% or more. The city influences act on heavy rain instances leading to more heavy rainfall events. Figure 7 is a schematic of the summer rainfall pattern from recent years at Chicago, showing the generalized dimensions of the urban-induced high rainfall area of 13.0 inches. Also shown are low rainfall areas related to lake influences. Of some importance to the total water resources of the area is the fact that the urban-induced increase in rainfall, an average of 1.5 inches more in a summer, covers nearly 500 sq miles of the urban area, as well as over the 1100 sq miles of the lake. The additional water, on the average, is 41 billion gallons per summer. This is a sizable percentage of the amount normally diverted from Lake Michigan in a given summer. One can react to this average rain increase as a potential benefit to the regional water resources.

We found a 76% increase in the frequency of 1-inch rain events in Chicago; a 33% increase in the frequency of 2-inch rain events in the city; and a 14% increase in the number of 3-inch or heavier rainfall events. These increases are in relation to frequencies in the rural areas around the city. Furthermore, we found that when northeastern Illinois areas experienced a 1-day rainfall that produced a point amount of 1 inch or more anywhere we discovered that 50% more rainfall fell on these days in the city than in the rural areas, on the average.

Our radar studies of summer rainfall allowed us to focus on rainfall rates over the rural area, the lake, and city. For heavier rates of > 6 mm per hour, or 1/4 inch or more, the city center experienced 40% more events in summer than did the upwind rural area west of Chicago. Thus, Chicago experiences more heavy rain rates than do surrounding rural areas.

The Water Survey also studied the northeastern Illinois raingage data, based on the 1949-74 period, to develop updated detailed rainfall rate frequencies. Figure 8 shows the patterns of the maximum 3-hour rainfall amounts expected to occur at least once every two years. There is a peak over the city, and then on the smaller scale inset map, twin highs within the city. Comparable patterns existed for longer duration rain values and for longer occurrence intervals.

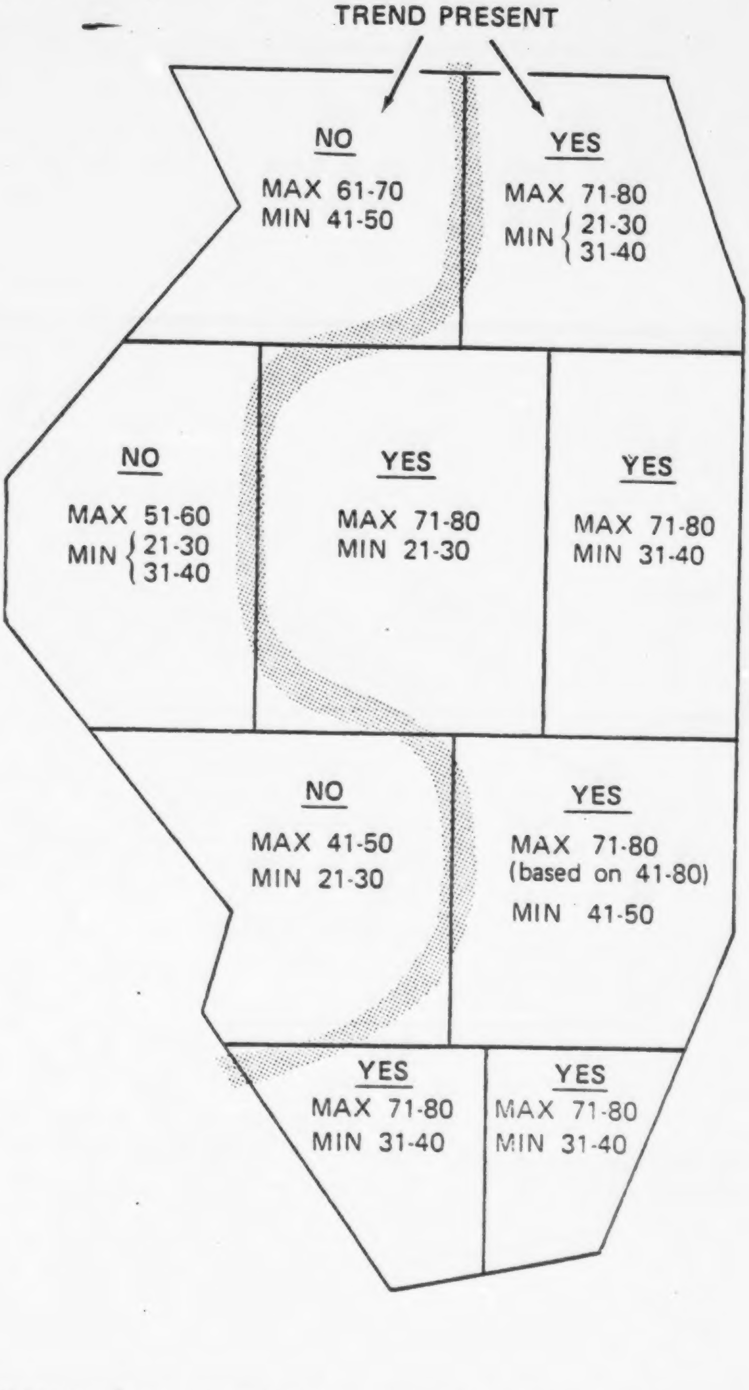

TREND PRESENT
NO
MAX 61-70
MIN 41-50
YES
MAX 71-80
MIN {21-30 31-40
NO
MAX 51-60
MIN {21-30 31-40
YES
MAX 71-80
MIN 21-30
YES
MAX 71-80
MIN 31-40
NO
MAX 41-50
MIN 21-30
YES
MAX 71-80
(based on 41-80)
MIN 41-50
YES
MAX 71-80
MIN 31-40
YES
MAX 71-80
MIN 31-40

Figure 4. Presence (yes or no) of up trends in district frequencies of > 2 inch rain days for 1921-80, along with decades of maximum and minimum values.

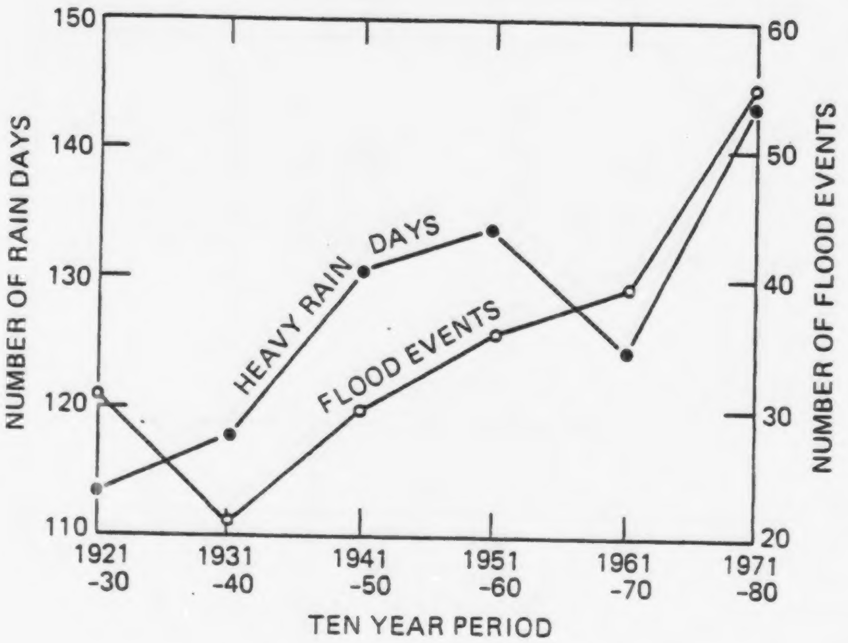


Figure 5. Statewide values per decade of heavy rain (> 2 inch) days and flood events, 1921-80.

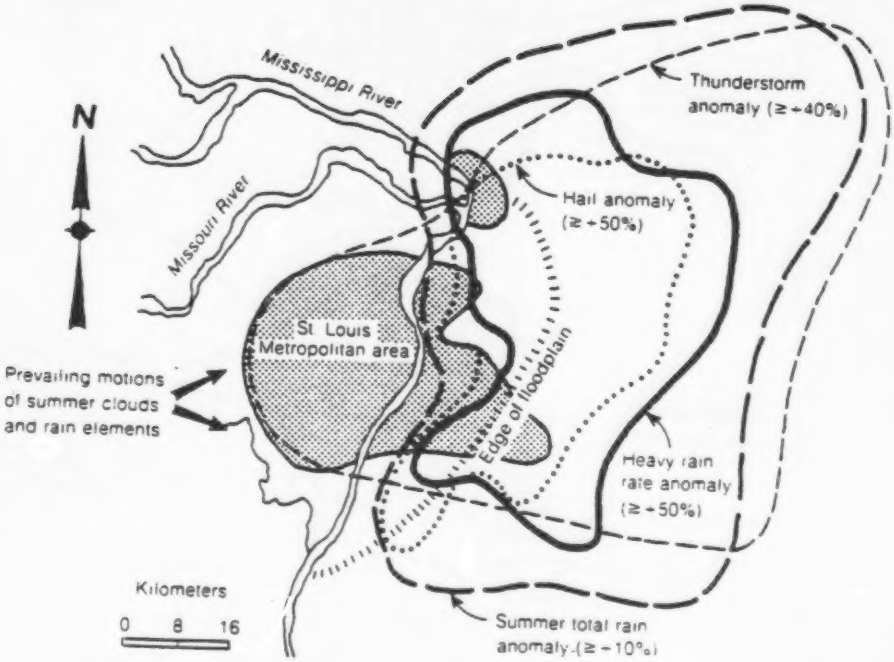
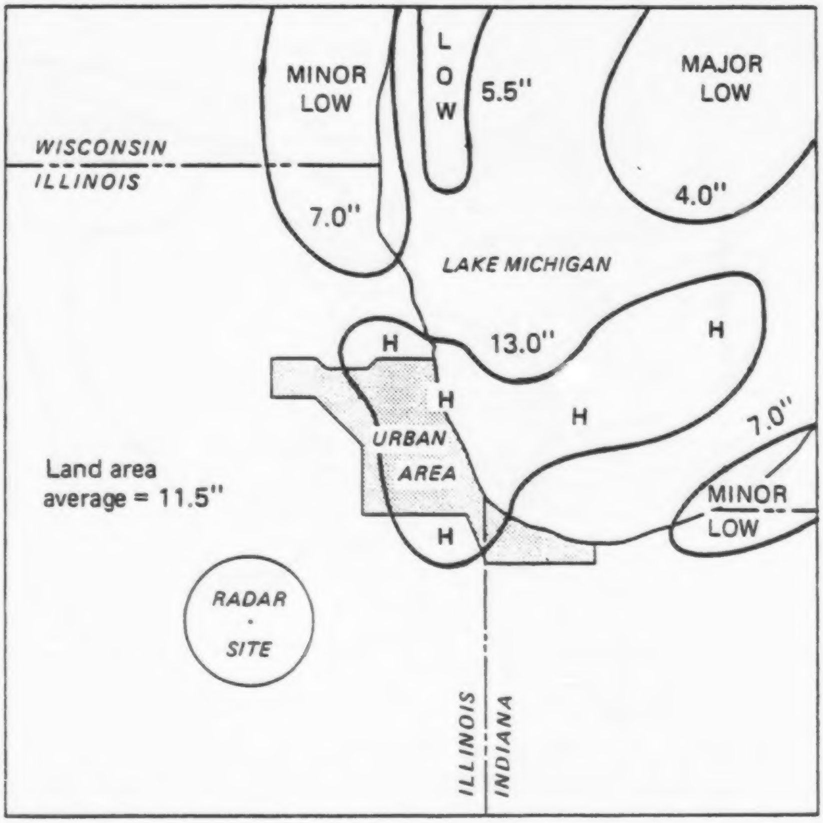

Mississippi River
Missouri River
N
Thunderstorm anomaly (≥+40%)
Hail anomaly (≥+50%)
St Louis Metropolitan area
Prevailing motions of summer clouds and rain elements
Edge of floodplain
Heavy rain rate anomaly (≥+50%)
Kilometers
0 8 16
Summer total rain anomaly (≥+10%)

Figure 6. The local anomalies found in summer rain and severe storms at St. Louis, Missouri.


MINOR LOW
LOW
5.5"
MAJOR LOW
WISCONSIN
ILLINOIS
7.0"
4.0"
LAKE MICHIGAN
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13.0"
H
H
H
URBAN AREA
7.0"
Land area average = 11.5"
MINOR LOW
H
RADAR SITE
ILLINOIS
INDIANA

Figure 7. Schematic of the average pattern of summer rainfall.

Table 2 shows 3 sets of values based on the 2-year and 5-year recurrence intervals for 1-hour, 3-hour, and 24-hour rainfall values inside Chicago. These were selected from 3 sources often used in design. However, each ~~has~~ different data base periods. This helps reveal how return rainfall values have increased with time. One set of values is from the Weather Bureau Technical Paper 40, a standard still in wide use but now 20 years old. Another set are from Water Survey results published some 20 years ago and based on 1901-58 data. A third set of values is based on recent 1949-74 data from our most recent studies. All of these tabular values are for a point in the central Chicago region. The comparison of values from the early 1901-58 data with those from the 1949-74 data, reveals the more recent rainfall frequency values are markedly higher than those based on the early data, as shown by differences in the table. Presumably, the higher values in the more recent 25 years reflect both the growth of urban influences and natural up trends in precipitation. Regardless of cause, they do indicate a marked upward shift.

The "percent increase" in rainfall caused by Chicago and St. Louis depends on whether one is looking at 1) rainfall rates of varying durations; 2) the frequency of heavy rain events of different magnitudes; 3) the amount of rainfall produced by heavy rainfall events; or 4) some other classification. It is impossible to present a single percentage figure, but the increases are large, generally in the 20 to 50% range.

Regardless of how these increases are caused, large metropolitan areas are receiving more heavy rain rates, more heavy rainfall events, and more rain when there are heavy rains in the area than do the rural areas or than the city did many years ago. The percentage increases in all the various rain categories are quite large and therefore significantly impacting both operations of water systems and the design of water management facilities.

SUMMARY

Given these substantial changes in flood-producing conditions due to climate, one can and should pose the question of "what can be done " One immediate reaction is to say that we can not alter the processes of natural changes in climate. Some efforts to modify the weather have been established but nothing that would relate to altering the flood-producing rainstorms. In facing the urban influences on rain that exist in the Chicago and St. Louis areas, we find that it is the totality of the metropolitan area that produces the change. Clearly, one can not remove the influence of Chicago on the atmosphere.

Thus, we must adjust to these natural and manmade changes in precipitation and temperatures that are causing an increase in flooding. However, one way to address this is to react and adjust to them in an intelligent fashion. Several things can be done to improve our adjustments to increased flooding. Some of these are recommendations in the 1983 Illinois State Water Plan Report for 1981.

Table 2. Comparison of Rainfall Frequencies from Different Sources for the Center of Chicago.

Period of data used	1-hour Rain (inches)		3-hour Rain (inches)		24-hour Rain (inches)	
	2-year	5-year	2-year	5-year	2-year	5-year
1938–57(3)	1.40(1)	1.70(2)	1.70	2.20	2.70	3.40
1901–58(4)	1.25	1.65	1.50	2.00	2.60	3.40
1949–74(5)	1.60	1.90	1.90	2.40	2.90	3.60
Difference of (1949–74)–(1901–58)	0.35	0.35	0.40	0.40	0.30	0.20
Percent $\frac{\text{difference}}{1901-58}$	+28	+21	+27	+20	+12	+6

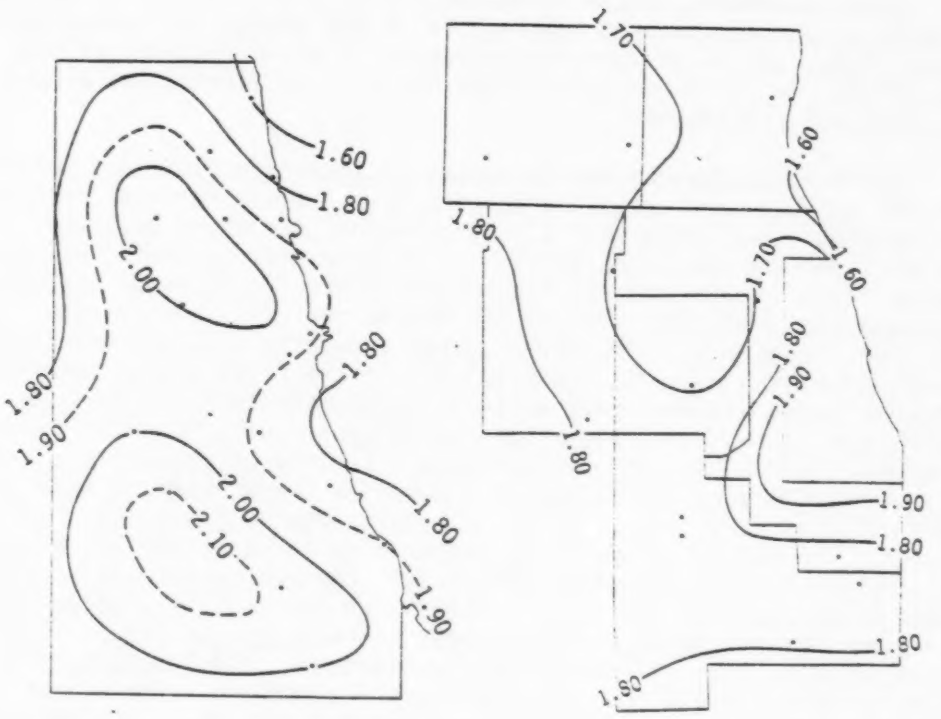
(1) 2-year recurrence interval; the value expected to be equalled or exceeded at least once every 2 years.

(2) 5-year recurrence interval.

(3) from U.S. Weather Bureau Technical Paper 40, "Rainfall Frequency Atlas of the U.S.," published 1961, based on national analysis and fitting of data from 1938-57.

(4) from Illinois State Water Survey Technical Letters 1 (1960) and 13 (1970). Based on all available historical data in Illinois for 1901-58.

(5) from Illinois State Water Survey Report of Investigation 82, "Hydrometeorology of Heavy Rainstorms in Chicago and Northeastern Illinois," using 1949-74 data.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1.80
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1.60
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1.70
1.60
1.80
1.90
1.80
1.90
1.80
1.80
1.80

3-HOUR MAXIMUM RAINFALL FOR 2-YEAR RECURRENCE INTERVAL

Figure 8. Patterns of 3-hour rainfall values expected to occur at least once every 2 years in northeastern Illinois.

One of the first and foremost things to do is to develop awareness of the shifts in the rainfall climate. Unfortunately, the translation of information on altered climate that is leading to more flooding into usage for design and operations in water resources has been slow. Adoption of altered rainfall frequencies in hydrologic design and operations appears to have been negligible. Regardless, the increased flooding events in Illinois over the past two decades have now raised the problem to the level of awareness and concern. Awareness can come to play through use of the types of information and documents such as the Water Survey and the Division of Water Resources presents.

Given awareness, there is the related action item. That is, where possible, we need to make adjustments in the designs of future water facilities, and in the current operation of water systems, as soon as possible. This will require larger drainage facilities and altered operational procedures.

Another recommended way to adjust to increased flooding, particularly in the metropolitan areas, is to seek more precise rainfall prediction and monitoring. Real-time rainfall information, including accurate predictions and real-time monitoring of over-city rainfall, is critical to urban flood adjustments and the optimal operation of urban drainage systems that have some storage and operational flexibility, such as that in the Chicago area. The Water Survey conducted a 3-year development and demonstration project in the late 70's in the Chicago area involving two sophisticated weather radar systems to demonstrate the capability for a dedicated man-machine system to provide highly accurate heavy rainfall information for the metropolitan area. In 1979 we conducted a 2-month demonstration such that every 30 minutes we transmitted to MSDGC data on any rain over the city, and rain forecasts for 30 minutes up to 6 hours ahead. The median error of the 2-hour rain forecast for 197 storms indicated that for sub-areas of Chicago, the mean error was only .09-inch with heavy rains of 0.3 to 1.5 inches. We are in full agreement with the conclusion from the ASCE which states, "newly develop capabilities for measuring and predicting rainfall by means of digital radars shows considerable promise for the improving of automated sewer system operation and for enhancing metropolitan flood warning systems." Implementation of a dedicated radar-forecasting system in the metropolitan area of Chicago appears to us to have considerable merit in better flood water management.

Because of both natural and manmade causes, northeastern Illinois has been and will likely continue to experience more flooding than most older rain design values would suggest. This causes more floods and longer durations of the floods. A rain that was once considered a 5-year occurrence event is basically now a once in 3-year event. Thus, there are fundamental changes to be addressed.

One should consider adjustments in use of more correct, updated rainfall values, both in the design of future water structures, and in the operations of water control systems.

There is great potential, if funding can be found, to provide what we believe to be accurate heavy rain forecasts and monitoring for urban areas using a dedicated radar system. We think this would be a wise investment.

DESIGN METHOD FOR RELIEF OF SANITARY SEWERS WITH INFLOW/INFILTRATION EXCESSES

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All sanitary sewer systems receive increased flow during wet weather conditions due to the entrance of storm water. The design and construction specifications allow for a nominal amount of additional peak flows due to the entrance of storm or ground water. Over the years the design allowances are written in an effort to reduce the quantity, but most sanitary sewers that have been constructed up to now receive excess quantities of infiltration and inflow (I/I).

When enough excess I/I enters the sewer, its capacity is exceeded and surcharge occurs. Surcharging results in flow into basements, overflows into the storm sewer system (where there are often illegal connections made) and out the top of the manholes. This condition is unsatisfactory because it presents a health hazard, pollutes streams, increases significantly the quantity reaching pumping and treatment facilities, and causes property damage.

The sources of I/I are many and varied. The easiest sources to identify and eliminate are connected roof and storm drains. These can be detected by smoke and/or dye testing. Often these sources contribute heavily to the quantity of excess flow, and the necessary efforts should be expended to remove them.

Other sources of I/I are footing drains, cracked or broken pipe, pipe joints, field tile connections, manhole defects including pick holes in lids, joints, pipe connections, etc. Where such I/I sources are identified and where it is cost-effective to do so, these defects should be corrected. It has been determined by experience that it is usually not cost-effective to research many types of defects and adequately correct them. These types include leaky joints, connected footing drains, and similar sources. This leads to a search for other means of eliminating the unsatisfactory performance of the sewer system.

Removal of downspouts and inlets from the sewer system and correction of other deficiencies including internal sealing of pipe joints and sealing manholes often do not produce the expected results of significantly reducing excess sewer flows. The reasons for this situation appear to be:

-- Service sewers represent one-half or more of the total length of sewers in a system. Often these sewers receive little or no inspection during construction. Repair of service sewers in place is difficult and expensive.

-- Footing drains, even though prohibited by ordinance often drain to the sewer system.

-- In place sealing of sewers often cannot be completely accomplished since horizontal cracks are difficult to seal and joints adjacent to tees or manholes must be by-passed.

-- When pipes are sealed in one location, water finds its way into the sewer by flowing through the soil along the pipe until another opening is found.

In order to confirm the importance of service sewers in the excess flow problem, we have conducted in-place exfiltration tests by plugging the sewer, temporarily disconnecting it from the house and measuring the amount of water necessary to maintain a small head on the full segment. The results of such tests are very revealing.

The solution to the problem may include one or a combination of the following:

1. Construction of a New Sewer - If the sewer is in poor structural condition, then it may be advisable to replace the sewer. Such replacement may solve the infiltration problem as well as other problems.

2. Repair the Existing Sewer - Poor connections, broken pipe, insufficient grade, etc. are defects that cause infiltration and should be corrected anyway.

3. Provide Storage in the System - Storage facilities may be provided in the system to relieve the surcharging by capturing and holding the flow until flow returns to normal and then returning it to the sewer.

4. Require Users to Revise Plumbing - Backup into basements can be prevented by disconnecting the basement drain and installing an overhead sewer to serve the floors above. Seepage and other water can be removed from the basement by a sump pump.

5. Construct Relief Sewers - This solution simply provides the additional carrying capacity of the sewer system to transport extraneous excess flows to an outlet.

Selection of the rehabilitation program best suited to a sewer system is generally established by facilities planning that incorporates collecting of field data, obtaining records and accurate details of the system, studying alternatives for correction of problems and making cost-effective determinations. Assuming that a study indicates the solution will be a relief sewer, quantifying the I/I is necessary for its design. Crawford, Murphy a Tilly, Inc., Consulting Engineers devised one method for designing sanitary relief sewers that appear promising. An explanation of this method follows.

The basic premise of the method developed by CMaT is that there is a uniform relationship between the volume of rainfall and volume of excess flow entering the sewer and this can be determined from field measurements. Therefore, the first step is to obtain field data that can be used to establish the relationship. This requires the installation of a recording rain gauge in the vicinity of the sewer system and flow monitoring equipment in the sewer itself at several key locations. Rainfall and flows must be measured on a continuous basis over a period of time sufficient to obtain the relationship of time, dry weather flow, peak flows, and volumes. Rainfall information can be plotted in a manner similar to that shown on Figure 1. This is called a Rainfall Hyetograph and shows that for the example given a total of 2.15 inches of rain occurred between 9:00 p.m., August 25, and 8:00 a.m., August 26, 1975. The hyetograph also indicates hourly rainfall amounts.

Figure 2 is a plot of the actual flows in a sewer that corresponds to the rainfall event shown on Figure 1. Because the flows were monitored over a sufficient time period, dry weather flow in the sewer at this location was established and is plotted on Figure 2. The difference between dry weather flow and peak wet weather flow is the amount of I/I introduced into the sewer. Figure 2 is a typical hydrograph in the sewer at one location.

From this data, a relationship between the rate of rainfall and the rate of flow resulting from the consequent I/I was established for a study area. The total rainfall in inches is obtained from the hyetograph. The volume of I/I is determined in several locations in the system and for different rainfall events using the sewer hydrographs and subtracting the dry weather flow.

Figure 3 graphs the percentage of the volume of precipitation which flowed in the sewer at a given location versus the total precipitation on the tributary area. These observations suggested that the total volume of infiltration into sanitary sewers in this particular study area will not exceed nine percent of the total rainfall on the surface area tributary to the sewers.

This relationship can be expressed mathematically as:

$$V = 0.09RA\ (27152)$$

where V = total volume of infiltration, in gallons

R = volume of rainfall, in inches

A = area tributary to sanitary sewer, in acres

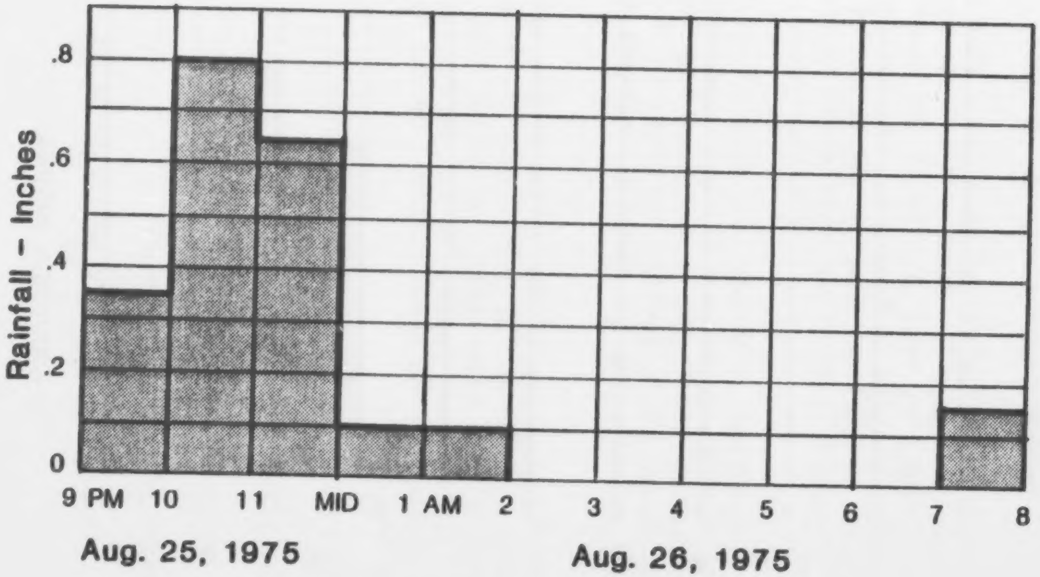


FIG. 1 - RAINFALL HYETOGRAPH - TOTAL RAINFALL 2.15"

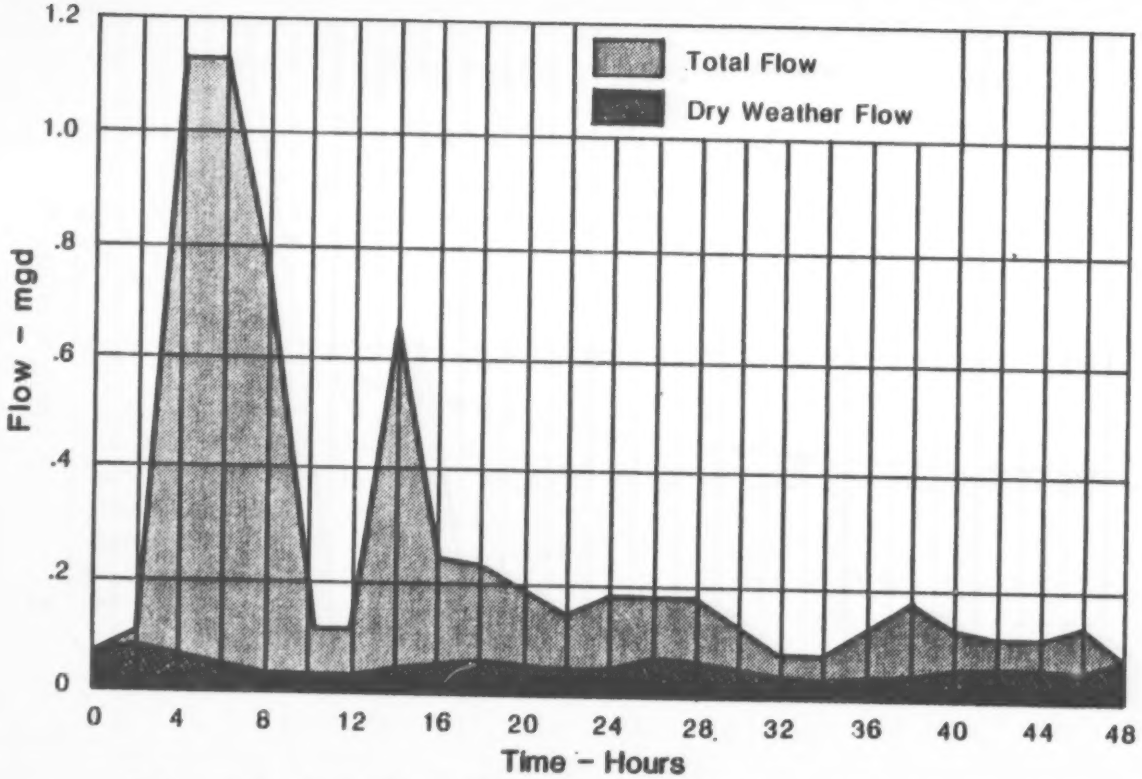


FIG. 2 - FLOW AT LOCATION "OA" STORM OF AUG. 25-26, 1975

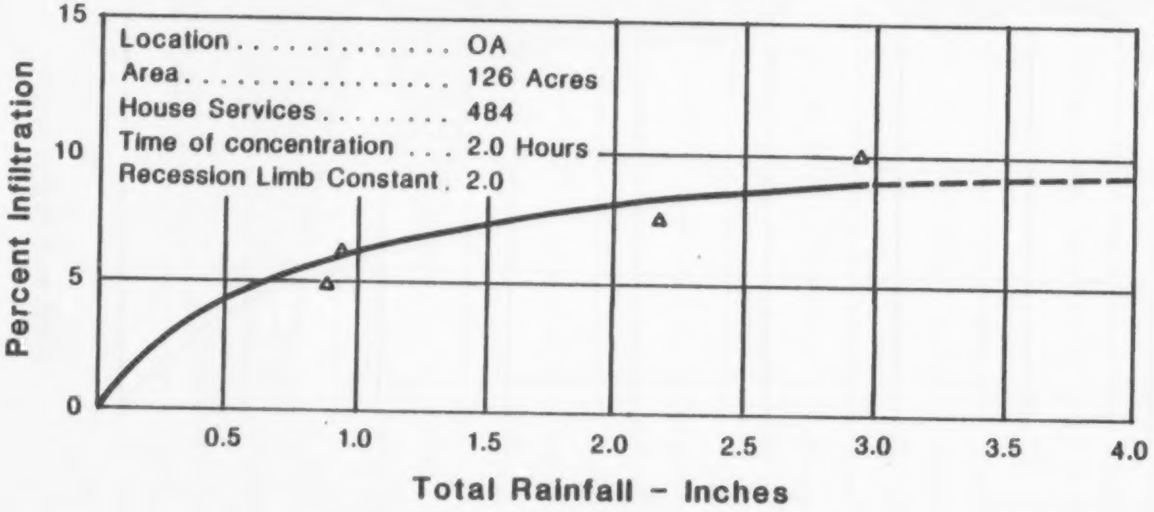


FIG. 3 - PERCENT INFILTRATION vs TOTAL RAINFALL

The constant, 0.09, is the percentage expressed as a decimal and 27152, a factor necessary to convert acres to square feet, inches to feet and cubic feet to gallons. By combining the constants, the formula becomes:

$$V = 2444RA$$

The two key constants were observed from studying hydrographs constructed from field data taken under conditions where sewers were not surcharged. In a given area, the relationship between both the time required to attain maximum I/I rates (Tc) and the time between the end of a rain and the end of I/I (KTc) are relatively constant. This is true in spite of variation in rainfall. Based on this observation, an empirical formula was developed which may also be used to determine peak I/I rates in gallons per hour to sewers under surcharge, as well as sewers with free outlets. The formula and its derivation is shown in Figure 4.

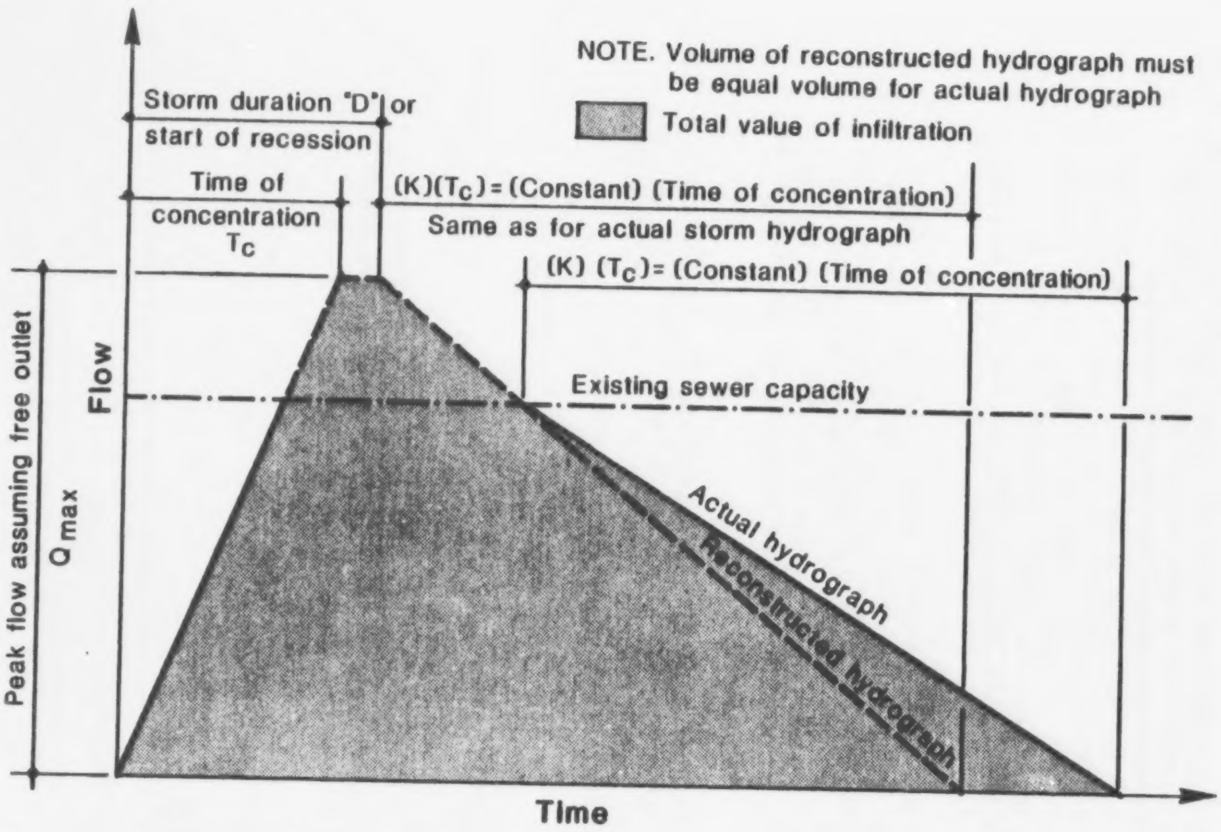
Assuming that hydrographs of actual rainfall events are available for a 126-acre area in which the design population is 1,055, the average dry weather flow has been determined to be 0.11 mgd and the peak, twice the average. It is desired to design for a total flow which would include the infiltration from a rainfall of 2.95 inches occurring over a period of 3 hours, equivalent to a storm which can be expected on the average of once in ten years.

From the hydrographs, a value of time of concentration, Tc, is selected as 2 hours; D is 3 hours and the value of KTc is 4 hours. Solving for K, it is 4/2 which equals 2. Therefore, the value of K - 1 is 1. Using the other formula for determining the volume of wet weather flow:

$$\begin{aligned} V &= 2444RA \\ &= (2444)\,(2.95)\,(126) \\ &= 908{,}435 \text{ gallons} \end{aligned}$$

Substituting this figure and the other values in the peak infiltration flow formula:

$$\begin{aligned} Q\text{max} &= \frac{V}{D + 0.51_{C}(K - 1)} \\ &= \frac{908{,}435}{3 + (0.5)\,(2)\,(1)} \\ &= 227{,}109 \text{ gal./hr.} \\ &= 5.45 \text{ mgd.} \end{aligned}$$


NOTE. Volume of reconstructed hydrograph must be equal volume for actual hydrograph
▨ Total value of infiltration
Storm duration "D" or start of recession
Time of concentration T_c
$(K)(T_c) = $ (Constant) (Time of concentration)
Same as for actual storm hydrograph
$(K)(T_c) = $ (Constant) (Time of concentration)
Existing sewer capacity
Actual hydrograph
Reconstructed hydrograph
Peak flow assuming free outlet
Q_{max}
Flow
Time

To reconstruct hydrograph to determine peak flow (Q_{max}) if free outlet were available :

1. Determine volume of infiltration (V) from actual storm
2. Determine time of concentration (T_c) and recession limb constant (K) from from hydrographs where sewer did not surcharge
3. Determine storm duration (D) from actual hydrographs
4. Compute Q_{max} as follows (Select $D \geq T_c$):

$$V = 1/2(Q_{max})(T_c) + (Q_{max})(D - T_c) + 1/2(Q_{max})(K)(T_c)$$

$$Q_{max} = \frac{V}{D + .5(T_c)(K-1)}$$

FIG. 4 - RECONSTRUCTION OF HYDROGRAPHS FOR STORMS CAUSING SURCHARGING

The total design flow would be the sum of the peak dry weather flow, 0.11 x 2, or 0.22 and 5.45, or 5.67 mgd.

This computation provides the design flow generated by the existing sewer system tributary to this point in the system. The relief sewer at this point would be designed to discharge the flow in excess of the existing system capacity. See Figure 5.

Similar calculations may be made at any point in the system by assigning the same hydrograph characteristics and taking into account the tributary areas, even though no field-flow measurements were obtained. The accuracy of the design may be improved by increasing the amount of field data obtained. Values for Tc and K used in the study were derived from observations taken during rainfalls which did not surcharge the sanitary sewers. Since Tc and K did not materially vary despite differences in rainfall, it was postulated that they are constants for any given locations. As such, they can be used to derive and empirically forecast the total volume of infiltration and peak infiltration rates for rainfalls of any magnitude.

The primary disadvantage of this method is the time required to obtain adequate field information. However, that field information provides the precise measuring and quantifying for design purpose, which is the primary advantage of the method of calculation.

This design method has been used for several relief sewers by CMaT, Inc., Consulting Engineers. One has been completed and has been in service since the spring of 1978. There have been several rainfall events that exceeded the total design rainfall quantity and with satisfactory results.

On April 11, 1979, 4.34 inches of rain fell in a 24-hour period. During the most intense period of the storm, flow in the sewer was checked at several locations. Relief sewers were not flowing full, although some of the existing laterals were. In December, 1982, approximately 7 inches of rain fell in a 24-hour period. Again there was no overflow from a sewer that formally overflowed from as little as 1 - 2 inches of rainfall in 24 hours. During this latter event, there was considerable surcharging in the lateral sewers, however. To provide further relief for lateral sewers the relief sewer can be extended where required.

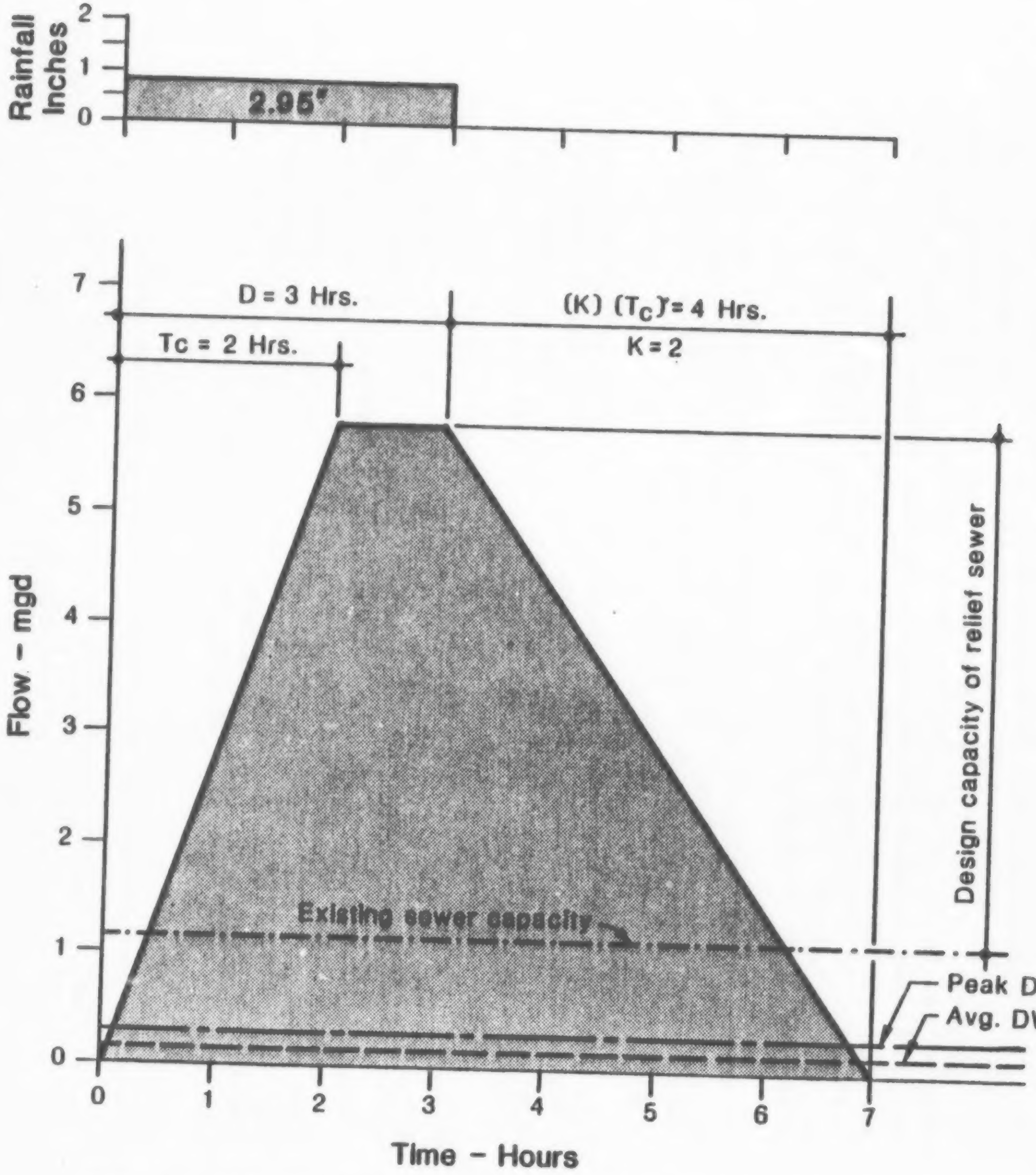


FIG. 5 - SYNTHETIC HYDROGRAPH FOR LOCATION "OA"

EXAMPLE COMPUTATION

GIVEN:

$A = 126$ Acres
Population served - 1055
Average dry weather = 0.11 mgd
Select rainfall and duration
$R = 2.95$ inches
$D = 3$ hours
$T_C = 2$ hours
$K = 2$

FIND:

Design Q_{max} for point "OA"
and Q_{max} for relief sewer

COMPUTATION:

$V = 2{,}444\ RA$

$= 2{,}444\ (2.95)\ (126) = 908{,}435$ gal

$$Q_{max} = \frac{V}{D + 0.5\ T_C\ (K - 1)}$$

$$= \frac{908{,}435}{3 + (0.5)\ (2)\ (1)} = 227{,}109 \text{ gal/hr}$$

$= 5.45$ mgd

Add peak dry weather flow

$5.45 + 0.22 = 5.67$ mgd

REFER TO FIG. 5

URBAN EFFECTS ON VOLUME AND PEAK FLOW RATES OF STORMWATER RUNOFF

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As urbanization takes place there is a tendency for rainfall-runoff volumes and peak flow rates to increase. This is due to several factors such as the decrease in pervious area and the increased hydrologic efficiency of storm sewer systems as opposed to natural drainage. There is less area for percolation and also a shorter time period available for infiltration to occur. From the perspective of the developer or community located near the headwaters of a stream, the most expedient thing to do is to get the excess rainfall away from the site as quickly and as efficiently as possible. However, this can cause higher peak flood discharges and result in increased stages on downstream property from the same frequency rainfall event. Thus average annual flood damages can be significantly increased unless stormwater systems are properly planned and designed.

What is the best way to prevent increases in downstream flooding due to urbanization? A commonly used method of trying to solve the problem is to require on-site retention storage in association with new development. The objective of retention storage is to keep the release rate at or below that which would naturally occur from the site and to store the excess volume until it can be released at the lower rate. The peak rate of flow is reduced but the hydrograph is flattened and the descending limb of the hydrograph is much longer. Depending on several factors such as the timing and direction of storm movement, orientation of the watershed, watershed size, and the relative size of the watershed area of the receiving stream compared to the watershed area of the area being served by a proposed storm sewer, retention of storm water can actually worsen downstream flooding conditions. A retention facility serving a sub-area downstream from the headwaters of a watershed may have a higher discharge at the time the peak on the receiving stream reaches the point of discharge than if no retention were provided. This is because the flattening of the hydrograph may require stormwater to be discharged at the time the stream peak arrives, when, without the retention, the sub-area may have been completely drained prior to the arrival of the stream peak.

How, then, can we determine when retention is desired and whether a proposed storm sewer system will improve the situation, leave it unchanged, or make it worse? Obviously, if we had complete, detailed hydrologic models of each watershed to be regulated, the task would be simple. The proposed modifications would be incorporated into the model and the change in peak flow rates predicted. But we seldom have the luxury of having that much data and often it is not justifiable to spend the resources to develop a model just for the analysis of a single proposed stormwater system. Therefore, we need a quicker, less expensive means of determining an appropriate design.

For the regulatory program of the Division of Water Resources we have established tentative guidelines to identify some situations where designers of stormwater systems need not be overly concerned with potential increases in downstream flooding. If the watershed area of the receiving stream is greater than 50 square miles and the area to be served by a stormwater system is less than one square mile, the Division does not require hydrologic computations nor consideration of the need for retention storage. Obviously, if the discharge from a small sub-area of a watershed is doubled or even tripled, it would not be expected to have a significant impact on downstream flows.

Also, if the proposed system will not increase the peak discharge from the area being served by more than 10% over the existing conditions, no further hydrologic analysis is required. This would allow a "worst case" cumulative impact of a 10% increase in peak discharge for the watershed, generally assumed to be insignificant.

If a proposed system fails to meet these criteria, the designer is required to develop hydrographs for the receiving stream and the outfall at a storm frequency equal to the design frequency of the outfall. These two hydrographs are then combined, utilizing a common time base. If the peak rate on the receiving stream below the outfall is increased, additional analysis is required. At this point an assessment of the potential for similar development (cumulative impacts analysis) within the watershed is made. The hydrograph is then recomputed incorporating the assumptions made regarding future urbanization. If the increase in downstream peak discharge rate is less than 10%, no further analysis is required. If the increase is greater than 10% it is necessary to compute water surface profile changes and to identify expected flood damages for both the existing and proposed discharges. Of course, at any stage of this process, retention storage may be utilized to meet any of these threshold criteria, as long as it is designed in a way which will assure that it will be effective at preventing an increase in downstream discharge rates.

This is where we find our greatest uncertainty. Short of the detailed hydrologic model referred to earlier, we do not have a quick, reliable method of predicting the impacts of retention storage in those situations where the drainage area of the area served by the storm sewer system is a significant portion of the drainage area of the receiving stream and the peak runoff from the sewered area will be increased significantly. Perhaps some additional research in this area and/or procedures development will lead to a solution.

DEVELOPMENT OF A STORMWATER MANAGEMENT ORDINANCE AND PAMPHLET FOR THE STATE OF ILLINOIS

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Approximately two years ago my Commission was awarded a contract from the Illinois Department of Transportation, Division of Water Resources (DWR), to develop two manuals: (1) a stormwater management ordinance, and (2) a complementary stormwater management pamphlet. The purpose of the two booklets was to familiarize local officials and citizens with the need for and methods of dealing with surface water runoff. The impetus for this project was the seemingly lack of stormwater management information prepared for the layman. On the other hand, a considerable amount of information has been provided for the more technically inclined, e.g., engineers. Assisting the Commission in this project were the engineering firm of Black & Veatch, Inc., and Richard Thompson, J.D.

As a general guideline the ordinance and pamphlet were to be short, concise, yet comprehensive (a difficult if not impossible task). They were also to be keyed towards Illinois topography, political organizations, and laws.

The purpose of this presentation is actually twofold. First, I'd like to share with you some of the things we were made aware of as we developed the two manuals, particularly in regard to the types of stormwater regulations presently in force in Illinois municipalities and counties. Secondly, for those who have never seen the manuals and for those who have seen them--but for whatever reasons have yet to take the time to read them--I would like to briefly introduce their contents. The two manuals are relatively short but do require one's full attention when reading. I highly recommend that local officials take the time and read them in their entirety.

Three basic methodologies were utilized in the preparation of these pamphlets. The first involved an extensive review of reports, books, studies and other documents related to stormwater management. Included in the review were Illinois Statutes, local ordinances and court decisions in Illinois and elsewhere.

Secondly, to determine statewide awareness of stormwater problems and approaches to solving them, a survey of local governments, public agencies and engineering firms was accomplished.

Thirdly, the preparation of these documents was supported by the information and guidance provided by the DWR and its Technical Advisory Committee.

Next to the constant input provided by the DWR and its Committee, the most enlightening and valuable information was provided through the survey results. Questionnaires were sent to city and county engineers, public works directors, planners and public officials representing 120 communities and 38 regional and county planning agencies throughout Illinois. A total of 77 questionnaires were returned including responses from 64 municipalities and 13 county and regional planning commissions.

There were a total of 20 questions, most of which were objective and could be answered by a knowledgeable official in a matter of a few minutes. I won't go over all 20 questions and results, but will mention those which I feel are of somewhat greater significance. The complete results of the survey can be obtained from the DWR's office in Chicago.

- The first question was: Does your community have stormwater management regulations? Forty-five of the responses were from the Chicago area and the remaining 32 were from downstate. Only three communities from the Chicago area indicated they have no stormwater management regulations. However, each of these three noted that the Chicago Metropolitan Sanitary District (MSD) stormwater regulations apply within their municipal boundaries. While many of the other Chicago communities also belong to the MSD, they apparently chose to supplement MSD standards with their own.

  Thirty-six downstate communities/counties responded to this question. Unlike the Chicago area, however, only 18 indicated "Yes," they do have stormwater management regulations while 18 answered "No." Several responding "Yes" apparently were referring only to the Flood Plain Control Ordinance as required by the national Flood Insurance Program.

- The most common type of stormwater management regulations are found in supplementary subdivision regulations and stormwater detention ordinances. Most communities, however, regulate stormwater runoff through more than one mechanism. There is no apparent difference between Chicago area communities and downstate communities in the selection of instruments for regulating stormwater, although MSD provides an additional layer of regulations for the Chicago area.

  Slightly more than half of the regulations are based on both performance and design specifications. A relatively few number are based solely on performance standards. A definite preference was stated for including some design specifications.

- The vast majority of community stormwater regulations address storage. Of the 58 communities with regulations, 54, or 93 percent, provide guidelines for storing the water on site. The other 7 percent or 4 communities store water downstream. Although most communities use on-site storage there are significant variations in standards. Only the MSD provides any consistency by setting similar standards for all development within its multi-governmental jurisdiction.

- With very few exceptions, communities with stormwater management regulations require all major categories of construction and development to comply with their standards. The major difference between regulations is the size criteria. The minimum size of a residential development which has to comply with stormwater regulations ranged from 0 to 10 acres, with a 5-acre standard being the most common. Minimum size of commercial and industrial developments ranged from 0 to 5 acres with the 0-acre standard as the most common.

- With one exception, all communities with stormwater regulations required some type of management plans. The type and amount of information varies widely. Some communities require detailed plans and specifications, and identify the precise procedures to use. Others simply require sufficient information with which to evaluate the stormwater impact of the project. Most communities appear to require a considerable amount of data.

- The large majority of communities assume the sole responsibility for inspecting stormwater control facilities. A few communities, under certain circumstances, will assign the responsibility to the developer or a homeowners association. However, only about one-fourth of the communities assumed the sole responsibility for maintaining the facilities and another one-fourth of the communities always assigned the responsibility to either the developer or a homeowner association. The remaining 50 percent of the communities had provisions for either accepting responsibility or keeping it with the developer.

- Most communities finance the inspection and maintenance of stormwater facilities and the administration of the program via a combination of permit fees and budget appropriations. A few communities pass all or part of these costs on to the homeowners. Two communities finance inspections by assessing a fee on a homeowners association, equal to 1 percent of the cost of storm drainage improvements.

- Although the rational method is most frequently used by communities in determining the size of stormwater management improvements, 18 communities identified more than one method they would accept. The rational method is as popular in downstate communities (8) as in the Chicago area communities, where the MSD primarily uses the rational method.

  There is a significant difference between the design rainfall event used in the Chicago area and that used in downstate communities. With one exception, Chicago area communities answering this question reported using the MSD design standard of a 100-year rainstorm event. Only 2 of the 11 downstate communities, however, reported using the 100-year frequency. The remainder selected either the 50-year, 25-year, or 5-year frequency storm.

  This signifcant difference may be attributed to MSD selecting the U.S. Weather Bureau's definition of a 100-year storm, 6 inches in 24 hours, as opposed to using the Illinois State Water Survey's definition for the same frequency and duration 8.4 inches in 24 hours. Depending on the definition the MSD standard is either a 100-year storm or for a storm closer to a 25-year frequency.

- Fourteen of 22 downstate communities did not feel their existing regulations were adequate, as compared to only 11 of 43 Chicago area communities. Comments received from downstate focused on the need for more detailed regulations, particularly in design specifications and maintenance. The numerous comments received from the Chicago area generally centered on problems associated with large urban areas. Officials cited lack of adequate regulations relating to renovation of existing developments, the need for a regional stormwater management plan, the need to review and redefine minimum parcel size.

- Approximately half of the Chicago area communities responding considered stormwater management to be a problem, while 22 of 26 downstate communities consider it a problem.

STORMWATER MANAGEMENT PAMPHLET

The Stormwater Management Pamphlet was developed in conjunction with the Model Ordinance to ensure compatibility. In fact, the introductory chapters to the Model Ordinance are very similar to sections of the pamphlet with the exception that they are somewhat more technical in nature.

The Pamphlet is divided into six sections; includes 21 illustrations; and, in the back, references certain reports which should be of interest to local officials/citizens and indicates where to obtain them. The six sections and their general contents are:

(1) Background -- Provides a very basic description of the hydrologic cycle and what happens when man intervenes. For example, an illustration shows typical increases in runoff caused by increased pavement. Generally speaking, an increase in paved surfaces of only 10-20 percent will cause the amount of runoff to double and decrease the amount of infiltration.

This section emphasizes the point that the traditional approach of handling stormwater runoff has been to make sewer lines and ditches larger and larger to handle the increased runoff and thereby alleviate the immediate on-site problem. These approaches were acceptable at a time when urbanization was scattered and a certain amount of downstream flooding was tolerable. However, urbanization has progressed to the point that this approach is hard to justify environmentally, economically, or legally. Larger storm sewers and channels that carry stormwater away from the site often create more problems than they solve by increasing downstream flows. The various alternatives to this conventional method and the rationale for utilizing them are discussed in the remainder of the pamphlet.

(2) Legal Consideration -- A brief but excellent look at Illinois Drainage Law and recent court cases is provided in the pamphlet. A more detailed discussion is in the introductory section to the ordinance. This section discusses the three types of drainage law--common enemy rule, civil law rule (also known as the natural flow rule), and the reasonable use rule. It discusses how Illinois has adhered (in all but name) to the reasonable use rule. That rule, quite simply, prohibits anyone from unreasonably interfering with natural drainage to the injury of others. Units of local government, as well as private individuals and entities, can be sued if they fail to abide by this policy of reasonableness. Therefore, it appears that local government officials would be well-advised to adopt and enforce stormwater regulations designed to prevent unreasonable drainage practices by developers, other citizens, or the governmental entity itself.

Two of the court cases cited in the pamphlet are worthy of special note. The first occurred in 1974 when the Illinois Supreme Court handed down its landmark opinion in Templeton vs. Huss. Mr. Templeton, a farmer, sued Mr. Huss and his associates, the developers of a residential subdivision, and the Village of Oreana, which had approved the plans for the subdivision and accepted the dedication of the streets in it. Templeton alleged that Huss' development had increased the amount and rate of surface runoff flowing onto his land, thereby damaging him; and that the Village knew or should have known this would happen when it approved the plat and accepted the streets. Templeton could not prove, though, that the increased runoff resulted from diversion from another watershed. Consequently, the lower court followed the civil rule and found for defendants.

Templeton appealed the lower court decision to the Supreme Court, which oveturned it on several grounds. First, the Supreme Court stated that upsetting natural drainage by interfering with natural seepage (which was the situation in this case) is legally no different from interfering by changing the pattern of drainage over the surface. Secondly, regardless of the technicalities, interference with natural drainage cannot go "beyond a range consistent with the policy of reasonableness of use." Thirdly, it is irrelevant whether an unreasonable increase in runoff is caused by diversion from another watershed or by "the installation of septic tanks, the grading and paving of streets, or the construction of houses, basements, and appurtenances." Finally, if the unreasonable interference with natural drainage did, in fact, cause damage to the innocent landowner, then not only the subdivision developer but also the local governmental entity, which had approved the subdivision plat and accepted the streets, could be held liable.

In the second case, Powell vs. Village of Mt. Zion, the plantiffs were homeowners whose basements had been flooded due to the backup of the Village's sanitary sewer system. The defendants were (1) the developer who had allowed runoff from his subdivision to enter the sanitary sewer system, thus causing the backup, and (2) the Village which had not inspected the developer's work but had simply allowed him to connect his sewer system to the Village's. The Court determined that, even though the runoff was flowing through a sewer, not over the surface, nonetheless Templeton demanded that the amount of runoff be reasonable. Moreover, the Village could be held liable if it had accepted the faulty sewer system without complying with the inspection and approval provisions of its own subdivision regulations.

(3) Stormwater Management Measures -- This is the largest section in the Pamphlet and contains 17 pictures/illustrations of various structural stormwater management techniques. The purpose of this section is not to identify specific solutions to existing or potential stormwater problems but to introduce to the reader many of the various stormwater management techniques currently in use. The types of measures discussed and illustrated include vegetative cover for friction control and infiltration, diversions, terraces, drop structures, porous pavement, grass lined channels, and detention facilities including rooftops and underground storage, lakes, dry basins, and parking lot storage. Examples of each of these can be found in virtually any relatively large urban area. Each of them serves to control surface water in a manner as close to the natural conditions as possible. A major objective of stormwater management systems is to lower the peak and extend the amount of time when the rain falls to when it enters the downstream river.

(4) Considerations in Selecting the Measures -- While the design of a stormwater management system is generally done by engineers, certain questions must be answered before the engineers can start. The answers to these questions set the basic parameters for the community's system and therefore they must be decided by the municipal authorities. While this chapter does not answer these questions, it does discuss the factors that should be reviewed and what the stormwater management survey revealed are the common practices in Illinois.

1. How large a storm would the system handle? No one can afford the stormwater management system that will completely carry a "Noah's Ark" flood.

2. What techniques should be used to measure the amount of runoff from the design storm? Different techniques may yield different results and a community should settle on one so that all development is treated equally.

3. How much and how fast should the water be released from storage structures? A small release rate will require a bigger and more expensive structure while a large release rate may overload the downstream ditches and pipes.

4. Who will pay the costs of construction and maintenance?

5. Should the stormwater management plan include provision for maintaining or improving water quality?

6. Should the stormwater management system include provisions to reduce erosion and sedimentation?

7. Does the community have any aesthetic or safety preferences?

8. How can the new measures be coordinated with the existing system?

9. How can the new measures be coordinated with the stormwater management programs and facilities of other communities in the watershed?

(5) Operation and Maintenance -- Regardless of the amount of planning, engineering, and sophisticated design that goes into construction of the stormwater management system, if it is poorly or improperly maintained it will not continue to serve its purpose. Therefore, the maintenance becomes a vital part of the system itself.

This section identifies and discusses the major aspects of maintenance--the plan, who should assume responsibility, financing, inspection, and enforcement.

Probably the most controversial topic is: Should local government assume responsibility or should a homeowners association or other private body shoulder the burden? Responsibility will depend, in large part, on the components of the stormwater management system. It is usually conceded that local governments are best equipped to provide maintenance for components such as detention/retention facilities and underground storm sewer systems because of ready access to equipment, labor, and expertise. Certainly such activities as dredging and structural repair are beyond the capacities of private citizens to respond. However, "aesthetic" maintenance, such as grass cutting and removal of litter and debris, can sometimes be managed by homeowners associations or individual property owners if their obligations are clear and if adequate provisions are made for inspection and enforcement.

(6) Stormwater Regulations -- The sixth and last section identifies the regulatory controls available to local government to enable them to establish stormwater systems. In Illinois, there are no stormwater regulations adopted at the state level; instead, authority to regulate stormwater runoff has been granted to local governments.

The major regulatory controls which are discussed include zoning, subdivision ordinances, building codes, and free-standing stormwater ordinances.

MODEL STORMWATER MANAGEMENT ORDINANCE

As discussed previously, the Model Ordinance was developed in conjunction with the Stormwater Management Pamphlet. As such, the introductory section to the Ordinance is quite similar to material found in its companion document. The major exception is that the Ordinance's introduction section, the legal and engineering aspects of stormwater management, is somewhat more detailed and technical.

I'm not going to go over the specifics of the Ordinance. You can take one of the copies I have with me or obtain one from the DWR. What I do want to do is make a few comments regarding the Model Ordinance and Stormwater Ordinances in general.

The first point I must stress is that the Model Ordinance is just that--a model. Because of various geographic, economic, and political cirucmstances throughout the state, it's not feasible to develop an ordinance with one set of standards and regulations which are appropriate for all communities/counties. Therefore, it's up to each unit of government to supplement and/or amend as necessary. For those sections that require a standard, we provided a commentary identifying those factors which should be considered prior to selecting the specific standard. As a guideline we provided the range of standards and the most common standard being used in Illinois communities/counties as found in the survey. For example, the allowable release rates from a detention facility or other related site was reported by communities/counties in the state survey to range from 0.1 to 0.3 cfs/acre. The most frequently used rate is .15 cfs/acre.

The second point I'd like to make is that, in order to effectively implement a stormwater management ordinance, the unit of government will have to rely on someone with a technical background, e.g., a qualified engineer, someone who is capable of interpreting and evaluating information submitted for review. The only alternative is to simply accept the submitted material as being accurate and in compliance with the ordinance. Unfortunately, the review, interpetation and enforcement of stormwater plans is beyond the capabilities of most city/county boards.

EVENING SESSION

PANEL DISCUSSION: STORMWATER MANAGEMENT -- FUTURE DIRECTIONS FOR THE INTEGRATION OF QUALITY AND QUNATITY ISSUES, THURSDAY, OCTOBER 20, 1983

Moderator:

Michael L. Terstriep, Head Surface Water Section, Illinois State Water Survey, Champaign.

Participants:

Dennis Athayde -- Chief, Urban Nonpoint Sources Section, Implementation Branch, Water Planning Division, USEPA, Washington, D.C.

Ernest Cobb, Urban Studies Coordinator, Water Resources Division, USGS, Reston, Virginia.

Steve Black, Assistant State Conservationist, USDA, Soil Conservation Service, Champaign.

Ben Ewing, Director, Institute of Environmental Studies, University of Illinois at Urbana-Champaign, and member of the Water Resources Commission of the State Legislature.

Thomas Borchert, Assistant City Manager, Elmhurst, Illinois.

William A. Rice, Supervisor, Project Management Unit Planning Section, Division of Water Pollution Control, IEPA, Springfield.

David R. Boyce, Chief Floodplain Management Engineer, Division of Water Resources, Illinois Department of Transportation, Springfield.

Mike Terstriep -- How serious is urban stormwater pollution and does it warrent the expenditure of public funds?

Steve Black -- Sediment is a very serious problem in urban situations. Some of the erosion rates that we estimated in urban construction sites were 5-100 tons per acre per year and in some cases up to 200 tons per acre per year. This is ten fold the amount of erosion we would experience on Agricultural land. A rate of 75 tons per acre a year is equivalent to about 2000 cubic feet per year. This is equal to one railroad tank of sediment for every acreage of drainage. SCS feels sediment is a major problem not only on agricultural lands but also in urban settings where construction is underway. Once an area has been developed sediment delivered from soil erosion is minimal.

SCS also feels that flooding is a serious problem for sanitary systems and water quality. The quantity of flood damage that occurs in urban areas is substantial. SCS is involved in some floodwater management planning and watershed management planning especially in the Chicago area where we are addressing flood damage.

Bill Rice -- The Best Management Practices that the IEPA suggested in the Illinois Water Quality Management Plan emphasized the use of construction erosion ordinances and stormwater detention ordinances. The plan stresses that stormwater control is the responsibility of the local government.

It is the Agency's and Federal Government's responsibility to offer Technical Assistance to local governments. Design criteria which adequately address both quality and quantity issues must be made available.

Erosion is a problem in some urban lakes that have development occurring around their shores. We have observed both organizational and some private lakes, Bruce Lake in Chicago for example, in which construction site erosion is impairing the use of the lake. Many of these problems have not yet been discovered. There are many public supply lakes which are adjacent to urban areas which have water supply intakes in the same general vicinity as the urban dischargers. More information needs to be obtained in these lakes especially in terms of the lake sediment and lake water quality.

There are also serious problems where ordinances exist but are not enforced properly. Technical advice on how to develop erosion control programs and how to make these programs work effectively is necessary. Perhaps State Agencies can act as intermediaries, when there are conflicts between residents and the contractors that cannot be resolved, to ensure a timely decision which will benefit the water quality.

David Boyce -- The Division of Water Resources works primarily with water quantity issues. We do consider water quality somewhat, from the point of view of sedimentation and flood control facilities. We have not given a lot of thought to the integration of quality and quantity issues but I am sure that this is a topic we will be addressing in the future.

Ben B. Ewing -- I think it is clear we do not have an urban water quality runoff problem. If we have problems there are a lot of different site-specific problems. Therefore we may find that the only approach to them is through State and local governments.

As Dennis Atnyade stated, the USEPA uses 3 levels to classify a pollution problem. There is a problem if there is a loss of beneficial use, violation of criteria, and perception of a problem by the public. I think this is a classification which can be used for numerous environmental problems.

In terms of urban runoff the impairment of use seems rare and very localized. If the major problem is the violation of criteria, perhaps the real problem is in the standards. There is a tendency to use national standards which apply everywhere in the USA. These tend to be set for the most critical conditions and most sensitive species. They also include some margin of safety or a margin of ignorance so they are probably set to be conservative. More site-specific criteria are probably necessary. Last if the public perceives a problem then there is a problem. The solution to this situation may be public education which might cost substantially less than the proposed engineering management approaches that have been stressed.

The Institute for Environmental Studies conducted an intensive research on lead in the environment seven or eight years ago. The major focus of the study was on the effects of lead on public health. So if urban runoff is carrying toxic materials such as cadium, lead and copper to the stream this is a blessing to the people as a mechanism for moving these toxic metals out of the habitat. One part of the study examined a 74 square mile rural watershed north of Urbana-Champaign and the 12 sq. mile urban watershed draining Boneyard Creek. It was estimated that 10,000 kilograms of lead per year were emitted by automobiles in the rural watershed and 20,000 kilograms of lead per year were emitted in the urban area. About half of the 30,000 kilograms stay in the atmosphere because it consists of very fine particles. This material blows out of the region. Of course additional material blows into the area. The only portion of the exhaust which reaches the ground is that brought in by precipitation. This consists of 800 kilograms per year.

Approximately 15,000 killograms per year of auto exhaust falls out very close to where it is emitted. In fact only 3% of the rain-out examined reached the streams. Thus it was concluded that urban runoff is not an important factor in moving lead out of the human habitat and keeping it from building up. I would suspect that the controlling mechanism is the re-entrainment of the road dust by traffic. Streetsweeping may move these particles around and may add to re-entrainment.

My conclusion is that urban runoff pollution is only a local problem and that there are several reasons why it is not a bigger problem everywhere. One reason is the intermittant nature of the problem and the fact that it occurs at a time when the stream has a high assimilative capacity. Consequently there is a dispersion which dampens out the peak as it moves downstream. Secondly, there is a tendency for urban pollutants to associate with solids which makes them less available to the biological life.

Ernie Cobb -- There is evidence that there is a certain degree of degradation of water from urban runoff but that does not necessarily make urban runoff a serious quality problem. By the time the urban runoff reaches the larger streams we rarely have a problem. It is in the smaller streams and more local type streams where problems probably exist from urban runoff. But urban runoff is part of the mix that must be considered when we do have water quality problems.

Sediment is a problem around much of the country. There are methods for controlling a great deal of erosion in urban areas, but there are only a few states which have really implemented control measures.

This may be more of an observation of human nature than anything else but when I was on loan to USEPA for two years it seemed that if there were a possibility of money there was a problem and if there was not a possibility of money there was not a problem.

I believe that local choices and local roles must be considered when deciding if urban runoff is a problem or not. When defining a problem one cannot only consider numbers for standards criteria but must also consider local desires.

Tom Borchert -- Streetsweeping for stormwater pollution control has been shown to be somewhat ineffective and perhaps better used as a service for cosmetic appearances in the business districts, parking lots and residential streets.

Urban runoff is a problem in Elmhurst. Two examples follow. Stormwater runoff pollution is a large factor in sedimentation. The City of Elmhurst had to sign a maintenance contract with the Illinois Department of Transportation prior to a construction project involving Salt Creek. The contract states that Elmhurst is now responsible for maintaining the improved cross-section. Salt Creek has silted up for over a 1/2 mile section with sediment 2-4 feet thick. Early estimates indicate it will cost approximately $200,000 dollars to remove that material. We are not certain that the material came from Elmhurst, yet the local Agency by agreement is responsible for cleaning it up.

The City of Elmhurst has an elevated water tower at the intersection of Route 83 and St. Charles Road, with Salt Creek. When Salt Creek floods the entire intersections goes under water. Flooding is a serious local problem. There are 1,300 homes in the community located in the 100 year floodplain. We believe that the expenditure of public funds to alleviate that flooding is necessary and that increased detention to alleviate problems caused by the increased sedimentation is necessary.

Dennis Athayde -- I concur with Ernie Cobb if there is money available there appears to be a problem. If there is a no money available there doesn't seem to as much of a problem.

There are three levels on which urban runoff needs to be evaluated prior to being classified as a problem. There was only one out of 28 studies which had an impairment problem. But urban runoff does violate criteria and that is a problem. The question becomes is urban runoff a significant problem. I feel that it is probably more appropriate for you at a local level to tell us that you are having a problem. When one has to close a shellfish bay then we know we have a problem. In terms of flooding we definitely have a urban stormwater problem.

I heard some important steps that we can take to aleviate runoff problems. One the Agency favors is technical assistance. As a matter of fact technical assistance has been approved in those areas where people want to look at the problem further. The technical assistance we are preparing is aimed at the State level. We are trying to transfer what we are learing from the NURP projects and get into a form that can be used on the State and local levels.

Yes, urban runoff mandates the expenditure of public funds. A more important question is how much money? From where I sit I don't see any construction grant type of program for Urban Runoff. We don't need 356 billion dollars for it, I doubt if we need 90 billion for it, but we might need 10 billion. Long Island has closed shellfish beds and if these are to be reopened it will cost 75 million dollars. We need to find these other Long Islands and if it is cost-effective, we should clean them up. I should add the Long Island Shellfish people were asked if they wanted to clean-up the Shellfish beds and they said no if the beds reopen the price of shellfish goes down.

Mike Terstriep -- Some interesting things came out of the discussion. Someone mentioned local priorities and we are certainly hearing this tonight. We have talked about flooding and sediment quantity and quality more than sediment quality. Sediment seemed to be the most prominent concern as we went through the group. I would agree, we know we are degrading the sediment, but we do not know about the fate of lead and other toxics accumulating in the sediments. We may have a time bomb type of effect with sediment but I don't think we know that yet. It has been established that there is probably not as much a relationship between the water column and sediment as thought when we started. For the most part our studies were water column type studies and did not identify severe problems with urban runoff. I think the idea that urban runoff is site-specific is an important part.

Audience Question -- If there is a problem only when money is available, is there money available?

Dennis Athayde -- There is always money available.

Bill Rice -- What is the status of the Clean Water Act Amendments where Congress is attempting to get an implementation program for non-point source pollution control? What do you think will happen with urban runoff in the context of the bill? Also, if the states receive money, is it going to be the usual grant allocations where you have three years to spend the money?

Dennis Athayde -- Anything I say is conjecture because the program may not materialize. But there is work on the Hill in the Public Works and Environmental Committees to pass such a program. Basically, it is to amend 92-500 for the third time. The 1983 amendments would contain a new Section, 319, for nonpoint source control would be very specific on what is required. Basically, the States would have anywhere from 9-18 months to submit control plans for nonpoint source control based on their previous 208 Studies, 205g reports, 305b reports, etc. The first States to submit these plans will get the money which will range from 10 million dollars to 150 million dollars in implementation money. Matching funds will range from 25-50% and this funding is good anywhere up to five years starting at at five million dollars a year.

So this is what Congress is thinking about non point source today: they will be amending PL 92-5001 and there will be implementation funds. The planning phases are supposedly completed and Congress will not allocate funds for planning. Furthermore, the Congress is saying non point source. They are not saying agriculture, they are not saying silva-culture or urban runoff. They are saying non point source.

Irwin Polls -- So what they are actually saying is that urban runoff is a local problem. In this program, they do not appear to be allocating enough money to finance a solution. Does a problem have to become a national problem before you get money? Obviously, the waste treatment problem is comparable because it is really a local problem. Yet that was funded heavily. Five million dollars a year for the nation does not seem adequate.

Dennis Athayde -- Did I say that or did I say between five and one hundred and fifty million? There is no number that has been established. This is only what Congress is thinking about doing. The committees are working on the program. The full Senate still has to vote on it in order to implement any program.

We probably could get a lot more for our money by rehabilitating sewer systems and bringing combined sewer systems up to size so they wouldn't overflow. There is a lot that can be done by making such grants available to cities but that probably won't happen because that would be rewarding cities that let their systems fall apart and penalizing those cities that took care of their systems. Section 319 is aimed at the states and the money will go to the states.

Audience Question -- I have a question for the gentleman from the Soil Conservation Service. Are you continuing to use the Army Corps of Engineers as your technical advisor and why aren't they represented here tonight?

Steve Black -- We do have protection projects not only in the agricultural setting but also in an urban setting. We have several projects in Chicago. All these projects are handled through PL 0566, the Small Watershed Program.

Mike Terstriep -- I'll try to answer the second part of your question about the Corp not being represented. I was on the planning committee and I can assure you it was not planned that way. We emphasized water quality and nobody in particular from the Corp came to mind to invite. Their absence was inadvertent, I assure you.

Audience Question -- There are some very serious problems with sediment and sedimentation on the bluffs at Harding Ditch. I was under the impression that the Corps was doing all the work through the Soil Conservation Service and that there were monies available for extending the project ~~that~~ the Corps is doing in that area.

Steve Black -- There are some projects that we work up jointly with the Corp and we provide some information on what we call the land treatment phases. We provide alternatives for erosion control on the land. But as far as projects where we would be providing funding, we don't have any in the area you are talking about.

Audience Question -- If some of these are local problems, shouldn't it be up to the local people to decide whether there is a problem or not? Everytime there is a gathering of people like ourselves who deal with common experiences, there seems to be a concensus that the closer enforcement and implementation comes to the local level the less likely it is to occur. In my opinion and in the opinion of others, it takes some remoteness to accomplish enforcement and implementation.

Local implementation might occur if there is assistance from above. But I am concerned because the more people who say a problem is a local problem, the less likely that problem is to get solved.

Bill Rice -- A lot of times at the State and Federal levels, even on the county level, you try to create packages which enable one to look at the entire State and say this is how we are going to handle the problem just so you can administer a program with the 2 people you have. We don't have the time or manpower to do detailed studies. Consequently, the packages are designed so one can review the issue in a uniform way.

From a State point of view, not all the streams in the State are going to be fishable and swimmable because they are not perceived that way and they are not being managed that way. If a stream is channelized and is being used for navigation, or if it is being used for drainage, it is not going to be a recreational swim area. When you sit at the State level and try to make decisions about where to spend dollars to solve problems, you don't know where problems exist until you get very specific in different geographic locations. It takes the locals to identify the problem to the State. Then the State offers technical assistance. For example, the locals may perceive that they have a problem but don't have the technical expertise to tell if it is a problem. They may not know enough about the biology of the stream to know whether the habitat has been altered so much that they can never get the fishing use they desire. Everyone likes to think that the stream in their back yard is going to be fishable and that just might not be possible.

If there is a problem, it is up to the community to decide whether they want to spend their dollars. Even if it is a 50-50 match program with the state or federal government, there are still going to be local dollars spent and they are going to have to make the decision on whether they are going to go ahead with the project.

Audience Question -- That argument is only true if you assume that problems are not interrelated. What I am hearing you and others say tonight is that these problems are so entirely isolated that every local problem can exist without endangering nearby or adjacent communities. This is not always true. In fact, it is seldom true. This is a nice cop out for people who don't have the money or enforcement means to do something about the problem. What I hear you saying is that you don't have the means, the money, manpower or implementation responsibilities to correct the problem.

Mike Terstriep -- What do you perceive the problem to be?

Audience Answer -- I am worried from what I hear that urban problems are going to be dismissed rather than being solved.

Mike Terstriep -- I think the way the question was phrased was, is the urban pollution problem severe enough to use public funds to solve it. We all agree that there is some kind of problem. But before we start funding solutions or hiring more EPA staff, we must make an honest decision about whether the problem is serious enough to warrant this type of action. I don't think we have clearly established that.

Audience Question -- When you are saying public funds, you are implying federal public funds versus local funds.

Mike Terstriep -- It would probably be a combination of both if some program is implemented. Do you perceive that there is a problem from urban runoff?

Audience Answer -- I do.

Mike Terstriep -- In terms of standards or in terms of cost to beneficial use?

Audience Answer -- In terms of standards and in terms of how the standards are established.

Mike Terstriep -- That was another issue that arose that I wanted to address. Is the problem that we can't meet the standards or that the standards are too tight to be realistic?

Irwin Polls -- The standards are not applicable to the situation. State stream standards which are based on a 24 hour daily flow are being used to assess stormwater problems. This creates a real problem in Washington. If it has taken them 10 years to develop and establish standards that we are now using and someone comes along and says you need a whole new set of stormwater standards, I can see a lot of problems.

Audience Question -- Up to now, I really like what I am hearing. I don't know if you've had a change in position, but I think we have become so programmed to having regulations imposed upon us that we are programmed to think what do we have to do to comply? What I am now hearing is that situations must be evaluated on an individual basis and if you need technical advice, ask for assistance. We have operated for a long time in a different capacity with EPA being an enforcing agency instead of giving advice. I just wanted to comment that I am enjoing what I am hearing.

Toby Frevert -- You basically have a federal program which addresses urban stormwater. There has been at least some discussion that the results break down into three approaches to the problem: use impairment problems, a criteria problem, and possibly a public image or public value problem. I gather from this afternoon's session that a lot of these local NURP projects seem to have identified fairly frequent criteria problems that weren't necessarily established as real use impairment problems. How does the feedback from the NURP program get incorporated into the standards criteria setting elements of USEPA to come up with guidelines? If we have water quality standards on the books promulgated according to water use criterion, we review and indeed accept these as the water quality criteria. Maybe these standards ought to be looked at again and what is the criteria used to reevaluate these?

Dennis Athayde -- That is a tough one. We had some discussions early in the program with the water quality criteria people about whether the water quality criterion should be changed. The conversation went something like this. That is all very well and interesting but we really don't need to change the water quality standards. They are there for a purpose and they are there to measure the uses as a yard stick and if you violate them, well you violate them. We are not going to come up with any wet weather flow criteria. It is difficult to reason with people like that so we got nowhere.

Now case in point is with bacteria. Bacteria closed shellfish beds and threatened to close beaches. We get more and more evidence that bacteria from urban runoff is not the same as bacteria that is coming from wastewater treatment plants. We've had discussions with groups composed of public health officials and they say don't tell us that the criteria is not right, just give us a number and if we err on the side of safety, we don't have any problems. We don't want to err on the side of not being safe. In terms of urban runoff, we are talking about an economic problem. Is it a significant enough problem that we want to spend money to control it? I don't see any health problems associated with urban runoff.

Audience Question -- That's in the short term. Maybe in the long term with the sediments that may not be true.

Dennis Athayde -- It may not be.

Audience Question -- I think that statement is incorrect because I think the sediment keeps on relating to long term problems. When you look at the water in many streams, even sometimes during storms, it looks great but when you sample the sediment, you may get a completely different picture and you find out that a majority of the bottom material is being loaded during storms and is being deposited.

Dennis Athayde -- I would agree if you are talking about sediments in lakes but I would not agree if you are talking about sediment in streams. We do have some evidence about sediments in lakes, for example, Lake Ellyn. Don Hey analyzed the Lake Ellyn sediment according to toxic criteria and found it was not toxic. The way sediment is transported in streams if you are going to have a problem, it will be in the Gulf of Mexico.

Audience Question -- You might be able to say that about the center of the stream but what about along the sides of the stream where there is not a lot of flow but where there is deposition and most of the fish population is located.

Michael Terstriep -- The way I interpreted Don Hey's statement about the Lake Ellyn sediments was that it was borderline toxic and they found that in the lake itself not just in the fine particulate material.

Audience Question -- The NURP studies looked at all the conservative constituents. Did they also look at trace organics?

Dennis Athayde -- Yes.

Audience Question -- What were the contributions in terms of trace organics?

Dennis Athayde -- The projects examined 129 priority pollutants.

Audience Question -- And they were very minimal in terms of contribution?

Dennis Athayde -- Yes.

Mike Terstriep -- Wasn't that just in the water column?

Dennis Athayde -- Yes.

Gary Schaefer -- In terms of Lake Ellyn, we did analyze for the USEPA priority toxics and they tested negative for the entire system. We didn't find anything that was toxic.

Audience Question -- I'd like to pose a question on the implementation point. We were talking of sediment in Salt Creek in Elmhurst and whether or not Elmhurst is responsible for cleaning it out and whether or not they are the source for it. Does implementation mean assistance to them for cleaning the sediment out of the stream so that flooding won't occur or does it mean source control in Elmhurst to show that the sediment is not from there or does it mean source control further upstream so that the sediment they might eventually have to dredge doesn't accumulate.

Bill Rice -- It's more of a drainage issue I think than a water quality issue or it's an impairment of use.

Toby Frevert -- Isn't it also a contractual obligation? That was my understanding.

Tom Borchert -- In this case, by the contract it's Elmhurst's responsibility. I don't want to say that that is ethically correct but by the contact it is our responsibility.

Audience Question -- If we are talking about implementation assistance for non point source control, is sediment considered a pollutant because I believe it is a considerable problem. Implementing sediment control is going to be difficult especially if one community complains about flooding and the other says that's your problem.

Bill Rice -- Well, this is kind of like the 314 Clean Lakes Program. There are several phases. In Phase I of the Clean Lakes Program, they find out what is causing the problem. After a cause is determined, a dollar cost is placed on solving the problem, both short and long term solutions. There is no point in dredging the lake if the problem isn't eliminated. Public monies are not being spent wisely if you don't eliminate the source. So, first you discover the problem, then you must come up with the cost to solve this problem.

Mike Terstriep -- I think there is a consensus that there is a problem with sediment quantity and quality. Sediment quantity is obviously a problem that may not be directly related to our issues.

I think we all agree that there are some specific problems with urban pollution. It sounds like there may be monies available to fund some cost sharing between the local, State and federal governments to resolve problems that have been specifically identified.

We definitely have a problem with standards that are not being met by urban runoff. This is both a State and federal problem because standards will have to be changed or we will have to look the other way as far as violations are concerned. This is a procedural problem.

Are there other things which can be done on a community level, regional level or a State level to modify solutions that are already in place? For example, can we rebuild detention basins, rewrite drainage ordinances, or include other provisions in drainage ordinances. I know one thing we didn't hear today was that urban cleanliness can do a lot for water quality. This is one thing we can do at a local level for a minimal cost.

The standards problem has been a persistent problem that everyone agrees exists. I invite anyone to comment on this situation.

Dennis Athayde -- I really don't see the federal government making any changes in criteria or guidelines, that's all the criteria are, guidelines. The states are the ones who issue the criteria. In Massachusetts there is a wet weather clause. During storm events, the bacteria standard does not apply. I think Oklahoma also has a similar clause. There is no reason why states couldn't modify their criteria in this manner for any pollutant on a site by site basis.

Toby Frevert -- Are the people in stormwater helping to identify pertinent factors and is that detail going to be incorporated into the guidelines?

Dennis Athayde -- Yes, and we will be providing guidance to the states if they want it.

Toby Frevert -- The reason I asked is because it is, of course, up to the states to promulgate standards that will hold up under USEPA review and receive USEPA approval.

Mike Terstriep -- What about solutions other than standards modification? We have discussed technical modifications of basins.

Ernest Cobb -- We learned a lot from Lake Ellyn. I think there is a lot to be done just in terms of basins without any additional costs at all. Just common sense will tell you that the location of the inlet or outlet can make a difference. You would be surprised at the number of basins where this has not been taken into consideration. The type of outlet structure you use also makes a difference as does the type of pond you use. Wet bottom versus dry bottom ponds are important because the wrong kind of pond will just pass the sediment out of them. Thus, there are a lot of things you can do without much additional cost.

Mike Terstriep -- Would designing various systems be one area for federal funding?

Dennis Athayde -- Could be, I don't know.

Steve Black -- In the Soil Conservation Service, our basic mission is to assist with technical design or implementation of anything that will help control erosion. We work with municipalities mainly through our flood control work, but we do feel we are improving water quality through these efforts.

On flood control projects, we look at everything from a hydrologic unit basis. We feel that one of the most important factors in a flood control project is land treatment. In an urban situation, we will work with the municipality to develop erosion and sediment control ordinances where sediment will be controlled at the source. The more sediment we can control at the source, the better we are at trying to address the problem downstream. It is a lot more cost-effective to keep sediment on site than attempting to clean out of a reservoir that has been completed.

I think erosion and sedimentation control ordinances can be installed without what you would call a public expense. Some of the structural controls in flood control get to be quite costly. However, we can justify these on a cost benefit basis. We would not build something that did not have a favorable cost benefit ratio. We look at a package approach of controlling sediment at the source.

Audience Question -- Is sediment itself a pollutant or is it what's in the sediment that is a pollutant? If you have 30 tons of sediment moving off a site but it does not have anything in it, is that a pollutant because of the quantity or does it have to carry a certain amount of other pollutants?

Ernest Cobb -- There is a problem with sediment from the standpoint of scouring problems and the reduction of fish habitat. So sediment is a problem in itself. However, sediment is a major carrier of other pollutants too, so it is a problem both ways.

Audience Question -- We don't have a standard for sediment per se like we do for other pollutants.

Mike Terstriep -- Sediment as a suspended solid is a pollutant in itself and we do have standards in many cases.

Audience Question -- Are we convinced that detention is always the solution to erosion? Isn't it true that detention can actually cause degradation to channels downstream because of the greater length of time that there is flow in those streams downstream of the site.

Ernest Cobb -- The reason you get degradation is not because of the longer length of time the water is flowing but rather because you have trapped the sediment out of the water. Water has a certain power to pick up sediment. When the water leaves a detention basin, it has no sediment so it picks up sediment. You can see this in many places. I lived in New Mexico for four years and you can see this above certain road structures. Sediment has been deposited upstream from the road structure and several feet of scour have taken place downstream. This is the result of the stream losing its sediment load and trying to come back into equilibrium by picking up sediment downstream from the structure.

Audience Question -- Their explanation was that degradation would occur at the bottom of the stream channel depending on the velocity of the stream where the velocities are the greatest and not because of loss of sediment.

Ernest Cobb -- They are certainly right in that high velocities can cause scouring at the outflow from a detention basin. General channel degradation downstream of the basin, however, is more likely the result if the stream is trying to come back into equilibrium by picking up sediment until a resistant bottom is encountered.

Audience Question -- Well, back to my original question, detention is not always the answer to the problem.

Mike Terstriep -- Detention can cause many problems itself.

Audience Question -- It seems that one of the largest problems is the inadequate control of the velocity of the discharge at some of these outlets. It seems that the simulation of energy at discharges seems to be one of the personal failings of most of the amateur engineers that submit designs for these basins. Often times, only cfs is looked at, not the velocity of the discharge.

Gary Schaefer -- Another factor in this is that right now detention storage is managed by local ordinances. Thus, from a regional perspective, you have what amounts to a haphazard planning method where you are siting facilities for only very small watersheds on a site by site basis. And I think we can probably accomplish a lot more by looking at the problem from a regional perspective and trying to site a single facility for multiple uses. I have read papers by some authors who have talked about the problem of putting in too many of these small on-site facilities and in effect not gaining the benefit they started out with before detention. I can think of some economic benefits as well. A single facility would probably be a lot cheaper than all the small on-site facilities. Cost could probably be recovered by the municipalities or the county taking contributions from the developers. There is such a project underway in the City of Elgin.

Mike Terstriep -- Those kinds of regional solutions have the potential for building in quality improvements as well.

Gary Schaefer -- A lot of those small facilities are probably not performing for quality now.

Audience Question -- There is an energy dissipator on the market which can be used on basins to dissipate the water's energy and then there will be no erosion.

Mike Terstriep -- Well, there is a typical profile of a natural channel and if you put in what amounts to a check dam at some point on that natural channel you can create another profile that will cause degradation and aggravation just because of that structure.

I still can't help but say sediment seems to be the pollutant we worried about throughout this evening. Whenever we talked about urban stormwater, we seemed to talk about sediment. We talked about sediment quantity and quality and whether sediment is a pollutant. We established that sediment is a pollutant in itself.

We don't have a runoff problem or an urban problem, we have many runoff problems which are highly variable. I think I agree with EPA's method of defining problems. We also have discussed the intensity of the problem especially within the constraints of solving the problem. There is a lot of confusion about what the local role in solving urban problems should be and whether a solution should be mandated from above.

I am still concerned about the ultimate fate of all the urban pollutants we know are generated. I am concerned about the way we have been conditioned to live in an urban area. Are we at a point where we just can't see what urban streams should be because the spare tires, shopping carts, etc., came before us? Is the stream condition problem tied into this business of what we perceive as a problem?

Ben Ewing brought up an interesting point about the benefit of streams taking lead out of our urban systems.

We have also learned, or at least I have, that there is a legislative program being planned and perhaps an implementation program so there is legislative action.

Bill Rice -- I think one important note, as Dave Boyce said earlier, is that the Division of Water Resources is concerned only with flood control and that the Army Corps of Engineers isn't here because they deal with mainly quantity. But I think one important thing we must start thinking about when designing these projects is examining the different things that affect waterways in addition to quantity.

You must examine how you are going to affect the quality, quantity, and the habitats that are in these streams when we start projects. As long as the different water groups keep dealing with a single purpose, it is going to be conflicting with the others. I'm not sure you are always going to eliminate the conflict but I think you must keep these things in mind especially if the stream is going to be used for more than one purpose.

Audience Question -- I'd like to ask Steve Black a question. He stated that SCS would not build a project without a favorable cost benefit ratio. In an urban flood control program, would you estimate the water quality benefits as well as the flood control benefits? If so, how do you estimate the water quality benefits?

Steve Black -- I'd say the majority of the benefits on our projects are flood related. In fact, I don't think they consider the effects of wate quality at all in flood damage relationships.

Mike Terstriep -- You really can incorporate both water quality and quantity concerns into cost benefit analysis if we are willing to recognize the benefits of some of these things.

Audience Question -- I have a feeling that an important water resources research area is the development of methodologies for determining water quality benefits.

Mike Terstriep -- My sincere thanks to the panelists.

SESSION 2-A: COMBINED SEWER OVERFLOWS

A PERSPECTIVE ON APPLICABLE REVIEW CRITERIA FOR POTENTIAL CSO PROJECTS

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BACKGROUND

Combined sewer overflows (CSO's) and bypasses have frequently been cited as signifcant contributors to local water quality problems. At the same time there appears to be a general reluctance to address these contibutors as an integral part of a system-wide POTW pollution abatement effort. The reasons generally cited for excluding CSO's and bypasses from an overall plan often are the time and expense involved in implementing a full solution, or lack of information to adequately characterize the problem and thereafter justify its resolution in the face of competitive and better defined construction and control actions. I believe the time is now at hand for all cognizant agencies to jointly attempt to better analyze and clarify CSO and by-pass problems and to ensure that appropriate remedial actions are developed to address them.

One of the main concerns of those who have studied CSO and bypass situations is that they are often viewed in all or nothing terms, with little regard for the specturm of initiatives that can be taken to identify cost-effective controls and mitigation actions. Additionally, current NPDES permits not only allow CSO and bypass situations but often fail to require even the most rudimentary monitoring or planning to address obvious environmental problems. In recognition of this circumstance, the problems of bypasses and CSO's were identified in the Region V Environmental Management Report (EMR), and subsequently a strategy was developed that identifies a USEPA task force headed by Ken Fenner, Chief Water Quality Branch to address the issue.

The Region V CSO Task Force met in August and September and outlined a series of actions designed to better define the information at hand in the Region on CSO (bypassing is to be addressed later). The pertinent portions of the EMR and associated strategy, as well as the minutes of the last two Task Force meetings, were sent to the six Region V states with a request for an assessment of the CSO problem from the State's perspective. The fifth attachment to these state letters was a listing, derived from the latest needs survey, that identifies municipal discharges, by State, with known combined sewer overflows. Using available information and the best professional judgment of their own staff, the states were asked to idenify which CSO's are known to be, or are thought most likely to be, associated with Water Quality Standards violations and to prioritize the most significant CSO's.

Finally, the states were requested to desginate a staff-level contact person to foster timely coordination and to provide a mechanism for undertaking any follow-up actions which may become necessary in the future. To date, all the Region V states have indicated they will do their best to cooperate with us and to be responsive to these requests.

PRESENT CIRCUMSTANCES

Construction Grant Observations

1. Combined sewer systems remain a major source of water pollution, despite the fact that the wastes they carry may receive treatment most of the time. Problems arise during wet weather, usually following rain, when a combined system may overflow directly to a lake or river. Such overflow points and treatment plant bypasses are necessary design features to prevent damage to the wastewater treatment plant during periods of high flow. However, they can be a major source of pollution because the overflow often receives no treatment whatsoever, and because the high velocity of the flow scours the sewer pipes clean of previously settled materials. Combined sewer overflows can also be a source of long-term pollution in the receiving water because discharged solids may settle to the bottom and form sludge desposits. These deposits may continue to deplete the oxygen and cause other problems in the waterway during periods of dry weather.

2. EPA research emphasizes the importance of controlling CSO pollution. EPA performed two sets of hypothetical calculations in order to determine the relative contribution of pollutants from treated wastes and from bypassed overflows. The calculations were designed to answer the following questions: "If all dry weather sewer flows from areas with combined sewer were to receive secondary treatment as mandated by law, how many million pounds per year of each of five pollutants would be discharged from the treatment plants into natural bodies of water?"; and "For areas with combined sewers, if sewer flows following storm events were automatically bypassed and dumped into natural water bodies, how many million pounds each year of five pollutants would be released?"

The results of the calculations show the following:

- o Five-day biochemical oxygen demand discharged from CSO almost equals that from secondary treatment plant effluent;
- o Suspended solids discharge is approximately 15 times greater from CSO than from secondary treatment plant effluent;
- o Total nitrogen discharge and phosphate-phosphorus discharge from CSO are each much less than from secondary treatment plant effluent; and
- O Lead discharge from CSO is approximately four times greater than from secondary treatment plants.

3. Conventional solutions to CSO problems are expensive. They require building new facilities and implementing regional plans. EPA estimates the cost of controlling CSO sources to be at least $30 billion, not including the estimated cost of storm water control. EPA has already funded over approximately $1 billion for CSO planning and construction.

4. Program Guidance Memorandum PG-61 (Also known as PRM 75-34) summarizes USEPA policy on the use of construction grants for treatment and control of combined sewer overflows. PG-61 specifies that CSO projects can be funded only on a case-by-case basis after detailed planning at the local level. The detailed planning requirements are as follows:

   o Alternative control techniques which might be utilized to attain various levels of pollution control (related to alternative beneficial uses, if appropriate), including at least initial consideration of all the alternatives described in the section on combined sewer and stormwater control in "Alternative Waste Management Techniques and Best Practicable Waste Treatment" (Section C of Chapter III of the information proposed for comment in March 1974).

   o The costs of achieving the various levels of pollution control by each of the techniques appearing to be the most feasible and cost effective after the preliminary analysis.

   o The benefits to the receiving waters of range of levels of pollution control during wet-weather conditions. This analysis will normally be conducted as part of State water quality management planning, 208 areawide management planning, or other State, regional or local planning effort.

   o The costs and benefits of the addition of advanced waste treatment processes to dry-weather flows in the area.

5. In order for a CSO control project to be approvable for potential EPA funding, the final alternative selected following detailed planning must meet the following criteria:

   o The analysis has demonstrated that the level of pollution control provided will be necessary to protect a beneficial use of the receiving water even after technology based standards required by section 301 of P.L. 92-500 are achieved by industrial point sources and at least secondary treatment is achieved for dry-weather municipal flows in the area.

   o Provision has already been made for funding of secondary treatment of dry-weather flows in the area.

- The pollution control technique proposed for combined sewer overflow is a more cost-effective means of protecting the beneficial use of the receiving waters than other combined sewer pollution control techniques and the addition of treatment higher ~~than~~ secondary treatment for dry-weather municipal flows in the area.
- The marginal costs are not substantial compared to marginal benefits.

NPDES PERMIT OBSERVATIONS

1. Current NPDES permits for CSO points usually contain only highly generalized language authorizing a CSO event when flows exceed sewer system and/or treatment plant capacity. Some permits also identify each CSO point and further require the permittee to monitor total BOD_5 total suspended solids and flow during the discharge event.
2. There is no requirement or special emphasis in current permits for analyzing and maximizing operational control of existing combined sewer systems for the purpose of minimizing CSO discharging during wet-weather periods.
3. Water quality standards compliance is viewed principally from the standpoint of water quality criterion violations, with very little, if any, analysis of the attainability of the use specified in the standard.

FUTURE POSSIBILITIES

Consturction Grants Observations

1. As of October 1, 1984, no more than 20 percent of a State's annual allotment for construction grants can be spent on CSO control projects (see 40 CFR 35.2015(b)(iii) unless:
2. The Governor specifically includes in the State's priority system a category for projects needed to correct combined sewer overflows which result in impaired uses in priority water quality areas. (See 40 CFR 35.2015(b)(iv).)
3. Only CSO projects which meet the following additional requirements may be included in category 2:
    - The project must address impaired uses in priority water quality areas.
    - The impaired uses must be due to CSO's.
    - The State must demonstrate to the Administrator that the water quality goals of the Act will not be achieved without correction of the CSO's.

- o The demonstration must prove that significant usage of the water for fishing and swimming will not be possible without the proposed project.

- o The CSO project will result in substantial restoration of an existing impaired use.

4. Review criteria for projects included in category 1 above remain the same as those which are currently in effect.

NPDES Permit Observations

1. Key to timely progress on minimizing environmental harm linked to CSO events are the requirements that each combined sewer wastewater treatment plant system be operated as well as possible and that, for those CSO discharges with known or likely significant Water Quality Standards problems linked to CSO events, the most cost-effective solution be identified and implemented as soon as possible.

2. Region V staff are working to develop more specific NPDES permit language designed to facilitate improved combined sewer/treatment works operation and to maximize use of all available in-line storage capacity. Current plans are to structure permits for CSO discharge points to include general, interim and final requirements.

3. General requirements could include:

    - o An identification of each CSO location.
    - o A requirement to prevent connection of new stormwater sources to the system.
    - o A requirement to monitor and sample representative CSO discharge points for BOD, total suspended solids and flow.

4. Interim requirements could include:

    - o A requirement to develop and implement procedures for prohibiting new connections to the transport/treatment system when dry-weather flows reach 80% of the system's maximum capacity.
    - o A requirement to develop an operational plan, by a certain date.

5. Final requirements could include:

    - o Modification of the permit to include the approved operational plan as a condition in the final discharge conditions.

6. Water qualtiy standards compliance is viewed from the standpoint of use attainability, and this viewpoint requires analysis over and above those necessary solely to ascertain compliance with existing water quality criteria.

A BIOLOGICAL STUDY OF THREE STREAMS RECEIVING CSO FROM THE CITY OF MATTOON, ILLINOIS

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INTRODUCTION

This study was undertaken to determine the general condition of the biological communities in three streams: The Little Wabash, Riley Creek and Kickapoo Creek. All three receive combined storm overflow, (CSO), from the system of the City of Mattoon.

Collection methods in this study were all standard. Water samples were collected and measurements of water quality parameters were made according to the methods approved by the American Public Health Association and the U.S. Environmental Protection Agency. Benthic samples were taken with a Ponar Dredge and supplemented by grab samples in order to provide a more complete characterization of the stream. Fish populations were sampled by electro-fishing, seining, and using dip nets. Plankton samples were taken with a standard 118 mesh net. Due to space limitation, plankton data are not included in this study.

THE LITTLE WABASH DRAINAGE

Stations 1 through 4 were located on the Little Wabash, a small stream which flows southwest from the edge of the City. The location of stations was designated to provide an above-below characterization of the stream relative to the entry of CSO. The lower numbered stations are downstream, the higher numbered stations are nearer the headwaters. The overall distance between Stations 1 and 4 is about one stream mile. An overflow structure occurs on the stream immediately above Station 3. Station 2 is approximately halfway between Station 3 and Station 1. There are no homes on this part of the stream, it is surrounded by agricultural fields, and several active oil wells.

In the study area the Little Wabash is little more than an improved drainage ditch. The banks of the stream are steep, (it has been dredged) and are overgrown with weeds. The stream is less than a meter in width and a few centimeters in depth at the headwaters. It increases to a width of several meters and a depth of 100 cm. at Station 1. The bottom material varies, but is primarily silt and sand mixed with gravel.

Table 1. Water Quality Parameters Measured and Methodology Used

Temperature	Thermometer	Field
Chlorine	DPD	Field
Conductivity	Meter	Field
pH	Meter	Field
Dissolved Oxygen	Oxygen Electrode	Field
Hardness	EDAT Titration	Lab
Turbidity	See Standard Methods	Lab
Suspended Solids	Ammonia Electrode	Lab
Ammonia - N	Nitrate Electrode	Lab
Nitrate	Ascorbic Acid Reduction	Lab
Ortho - Phosphate	See Standard Methods	Lab
BOD_5^{20}	See Standard Methods	Lab
Total Coliforms	See Standard Methods	Lab
Fecal Coliforms	See Standard Methods	Lab
Fecal Strep	See Standard Methods	Lab
SPC	See Standard Methods	Lab

Table 2. Water Quality for the Little Wabash River - August

	1	2	3	4
Dissolved Oxygen (mg/l)	3.80	3.10	2.80	6.7
Conductivity (umho/cm)	880.00	940.00	2400.00	3600.00
Turbidity (NTU)	8.00	28.00	6.20	7.80
Suspended Solids (mg/l)	23.00	43.00	10.00	10.50
Ammonia Nitrogen (mg/l)	1.50	1.40	0.52	0.20
Nitrate (mg/l)	7.00	7.00	11.00	46.00
Ortho-Phosphate (mg/l)	0.85	1.10	3.30	0.12
Biochemical Oxygen Demand (mg/l)	14.40	12.60	12.80	4.90
Fecal Coliform/Fecal Strep	1.66	1.79	3.42	1.82
Total Coliform / 100 ml	2.0×10^6	2.0×10^6	$.0 \times 10^6$	2.0×10^6
Fecal Coliform / 100 ml	8.3×10^5	1.1×10^6	7.2×10^5	7.1×10^5
Fecal Strep / 100 ml	5.0×10^5	6.1×10^5	$21. \times 10^5$	3.9×10^5
SPC/ml	3.3×10^6	4.7×10^6	9.2×10^5	6.0×10^5

Table 3. Water Quality for the Little Wabash River - October

	1	2	3	4
Dissolved Oxygen (mg/l)	9.80	8.90	8.00	9.00
Conductivity (umho/cm)	940.00	980.00	780.00	780.00
Turbidity (NTU)	3.40	3.90	3.40	2.60
Suspended Solids (mg/l)	10.00	9.30	5.00	<3.00
Ammonia Nitrogen (mg/l)	0.36	0.18	0.19	0.18
Nitrate (mg/l)	10.00	46.00	54.00	48.00
Ortho-Phosphate (mg/l)	0.02	0.04	0.04	0.06
Biochemical Oxygen Demand (mg/l)	0.30	1.50	1.50	3.00
Fecal Coliform/Fecal Strep	4.33	0.48	2.75	0.58
Total Coliform / 100 ml	2.0×10^4	7.0×10^5	1.1×10^5	3.8×10^6
Fecal Coliform / 100 ml	1.3×10^3	1.4×10^5	3.3×10^3	1.1×10^5
Fecal Strep / 100 ml	3.0×10^2	2.9×10^5	1.2×10^3	1.9×10^5
SPC/ml	1.3×10^4	3.9×10^5	4.0×10^4	2.8×10^5

Table 4. Fish Populations of the Little Wabash River-August and October

SPECIES	STATION 1 Aug/Oct	2 Aug/Oct	3 Aug/Oct	4 Aug/Oct
Creek Chub	0/4	3/26	0/0	No Fish
Fathead Minnow	0/13	1(dead)	0/4	0/0
Longear Sunfish	0/1	0/0	0/0	0/0
Green Sunfish	0/1	0/0	0/0	0/0
Gizzard Shad	0/1	0/0	0/2	0/0

Table 5. Benthic Populations of the Little Wabash River - August and October

	1 Aug/Oct	2 Aug/Oct	3 Aug/Oct	4 Aug/Oct
Oligochaeta				
Tubificidae	21/190	164/356	240/353	514/150
Lumbriculidae	0/3		0/1	
Hirudinae				
Gastropoda			3/0	
Physa Sp	30/3	30/3	0/3	14/1
INSECTA				
Chironomidae	51/0	117/3	1/16	1/0
Odonata	0/1			
Simulidae	21/4	1/0		0/1
Culicidae	11/0	2/0		0/10
Coleoptera	0/1			

In the vicinity of Station 3 there are silt beds present. The stream may be intermittent at the headwaters where the sources of water are surface run-off and from drainage tiles from nearby farm fields.

In order to gain a seasonable aspect of the communities in the streams, samples were taken in August representing dry conditions in the area, and again in October, following several inches of rainfall. The data pertaining to the Little Wabash Drainage are presented in Tables 2 through 5.

The data for the water quality of the stations on the Little Wabash for the August sampling period indicate that no significant variation occurs in pH, temperature, hardness, or total hetrotrophs, (SPC). All other data indicate that a source of organic/fecal pollution enters the stream near Station 3 and that the effects extend downstream to Station 4. Values for biochemical oxygen demand (BOD) and dissolved oxygen (DO) show a characteristic inverted relationship. The values for turbidity and suspended solids, ammonia nitrogen, and ortho-phosphate also indicate such a probability. The bacteriological test results also indicate a source of enrichment, probably of human origin, especially the FC/FS ratio.

The water quality of the Little Wabash is improved in the October sample period. Several inches of rain fell in the days immediately before samples were taken. The values for BOD, turbidity, and suspended solids are all low, the values for DO rather high. Otherwise, it is noted that the values for nitrates is elevated. The agricultural activities in the area may be one source of nitrogen, as well as an increased activity of nitrification, as indicated by lower ammonia-nitrogen levels. It is possible that self-purification is occurring. The bacteriological data also indicate better water quality, with lower absolute values for the counts, and lower FC/FS ratios. The values are higher than expected for Station 1, an unexplained observation.

The Little Wabash is characteristically a small headwater stream in the area sampled and the fish species collected are common to such a stream. With a shallow, exposed, small volume of water, not many fish are expected, another fact consistant with the results of sampling the stream as shown in Table 5. The August samples were particularly depauperate. The October samples on the other hand contained several fish of species typical of this type of stream. Both the larger amounts of water following the Fall rains as well as the better water quality probably account for the differences. August populations were probably smaller because of water levels and poor water quality, causing the fish to avoid the area.

The benthic populations of the stream are presented in Table 5. Station 1 had a moderately diverse population with high numbers of several common benthic forms. The upstream stations become less diverse with the headwaters, Station 4, containing the least diverse population at all stations sampled.

Stations 3 and 4 were characterized by large populations of worms, predominantly *Limnodrilus hoffmeisteri*. By contrast, the worm population at Station 1 in the October sample consisted of large numbers and six different common species of worms.

Table 6. Water Quality for Riley Creek - August

	5	6	7	8	9	10	11	12
Dissolved Oxygen (mg/l)	5.50	4.30	2.50	2.30	0.40	6.20	1.30	0.50
Conductivity (umho)	560.00	590.00	610.00	660.00	740.00	680.00	560.00	590.00
Turbidity (NTU)	71.00	6.00	4.20	5.50	34.00	26.00	36.00	30.00
Suspended Solids (mg/l)	94.00	12.50	11.50	13.00	41.00	27.50	65.00	28.00
Ammonia Nitrogen (mg/l)	0.05	0.12	0.06	0.12	1.45	0.10	1.25	4.90
Nitrate (mg/l)	15.00	7.00	9.00	13.00	2.00	14.00	2.00	4.00
Ortho-Phosphate (mg/l)	0.11	0.17	0.07	.31	1.30	.44	1.15	0.75
BOD (mg/l)	4.40	1.90	2.10	6.40	24.00	9.60	64.00	48.00
Fecal Coliform/Fecal Strep	0.37	0.24	0.48	1.11	0.85	8.67	2.58	8.00
Total Coliform/100 ml	1.5×10^5	6.0×10^3	9.0×10^3	1.4×10^5	2.6×10^5	5.0×10^4	2.0×10^6	2.0×10^6
Fecal Coliform/100 ml	3.0×10^4	1.7×10^3	6.0×10^2	7.1×10^3	3.6×10^3	1.8×10^3	8.2×10^9	4.2×10^6
Fecal Strep/100 ml	2.4×10^3	2.8×10^4	7.2×10^3	2.9×10^4	2.8×10^5	3.9×10^4	2.6×10^6	3.0×10^5
SPC/ml	1.3×10^4	1.2×10^4	3.5×10^3	1.2×10^4	1.0×10^4	4.0×10^3	3.7×10^4	5.5×10^3

Table 7. Water Quality for Riley Creek - October

	5	6	7	8	9	10	11	12
Dissolved Oxygen (mg/l)	10.50	10.20	9.60	9.70	9.20	10.40	10.70	9.80
Conductivity (umho)	620.00	670.00	680.00	680.00	740.00	840.00	830.00	860.00
Turbidity (NTU)	17.00	9.20	9.20	8.50	11.00	1.40	4.40	1.50
Suspended Solids (mg/l)	15.00	6.70	<3.00	5.00	10.00	2.50	4.00	<3.00
Ammonia Nitrogen (mg/l)	0.07	0.10	0.11	0.34	0.20	0.03	0.47	0.05
Nitrate (mg/l)	56.00	52.00	46.00	46.00	44.00	40.00	13.00	4.30
Ortho-Phosphate (mg/l)	<0.01	0.06	0.04	0.04	0.02	0.02	0.06	0.06
BOD (mg/l)	0.40	0.20	0.40	0.30	1.20	not detected	3.50	1.50
Fecal Coliform/Fecal Strep	1.23	0.06	0.08	0.24	0.01	0.04	3.19	4.90
Total Coliform/100 ml	1.5 x 10^5	6.0 x 10^3	9.0 x 10^3	1.4 x 10^5	2.6 x 10^5	5.0 x 10^4	>2.0 x 10^6	>2.0 x 10^6
Fecal Coliform/100 ml	3.0 x 10^4	1.7 x 10^3	6.0 x 10^2	7.1 x 10^3	3.6 x 10^3	1.8 x 10^3	8.2 x 18^6	4.2 x 10^5
Fecal Strep/100	2.4 x 10^3	2.8 x 10^4	7.2 x 10^3	2.9 x 10^4	2.8 x 10^5	3.9 x 10^4	2.6 x 10^6	3.0 x 10^5
SPC/ml	3.7 x 10^5	6.3 x 10^5	5.8 x 10^5	4.9 x 10^5	1.2 x 10^6	3.9 x 10^5	>5.0 x 10^6	2.5 x 10^6

Table 8. Fish Populations of Riley Creek - August/October

	5 Aug/Oct	6 Aug/Oct	7 Aug/Oct	8 Aug/Oct	9 Aug/Oct	10 Aug/Oct	11 Aug/Oct	12 Aug/Oct
Silverjaw Minnow	0/7			2/0				
Bluntnose Minnow	13/29	48/64	12/62	57/14	3/9		0/4	No Fish
Fathead Minnow			42/15	22/0	12/3		0/1	
Black-Striped Top Minnow		4/2	0/24	1/10	0/1	0/3		
Stoneroller	7/22	3/0	3/0	2/0				
Creek Chub	19/28	8/1	7/4	32/0	6/0	9/0		
Creek Chubsucker		0/1						
Redfin Shiner	3/0	0/1	4/5	2/2	0/1		0/4	
Striped Shiner	2/1		1/4					
Orangethroat Darter	0/17	8/1	0/4	0/5				
Johnny Darter	21/10							
Blackside Darter	8/0							
Green Sunfish		3/3		0/1	0/1			
Longear Sunfish	1/0	9/2	5/2	0/1				
White Sucker	20/9							
Black Bullhead	1/0							

Table 9. Benthic Populations of Riley Creek - August/September

	5	6	7	8	9	10
Oligochaeta						
Tubificidae	2/8	25/11	25/11	13/91	62/353	307/ 92
Lumbriculidae						
Hirudinae				4/3		
Gastropoda						
Physa		4/21	5/2	10/12	7/6	7/5
Helisoma		1/21	0/7		18/5	
Pelecypoda						
Sphaerium				0/1		0/3
Sphaeridae						
Insecta						
Chirononidae	5/55	50/140	80/28	17/29	0/6	
Odonata	3/0	6/0	4/0	1/0	0/14	1/0
Simulidae	30/0	10/0	17/0			
Certopogonidae		1/0				
Culcidae		5/0	5/0	1/0		
Tabanidae		1/0				
Coleoptera	0/1				6/1	1/0

	11	12
Oligochaeta		
Tubificidae	60/455	0/60
Lumbriculidae	0/3	0/2
Pelecypoda		
Sphaeridae	2/0	0/2
Insecta		
Chironomidae	75/0	0/75
Simulidae	0/1	

The data in general indicate that the Little Wabash is effected by the addition of organic materials, likely of human origin, in the area of the stream where a CSO outfall is located. The stream shows physical and biological symptoms of disruption from that point, downstream for about a mile. At that distance, recovery appears to be occurring. Also, the presence of high water provides a reduction of these dry-weather conditions. The elevated values for certain of the water quality tests in the dry period indicate the possibility of sewage entering the stream during that period, therefore unlikely to be associated with CSO. That possibility should be investigated.

RILEY CREEK

Riley Creek has three types of stream environments. The most downstream station, Station 5, is a typical small prairie stream, with a well defined flood plain of mature trees nearly comletely shading the stream. The stream is several meters wide and has intermixed pools and riffles. The bottom is sand and gravel, with some silt in the eddys. Stations 6 through 10 represent a second stream type. The stream has been ditched for greater capacity, has no trees or shade cover, steep banks that are weed covered, and the surrounding area is farmed to the edge of the ditch. The stream varies around one meter in width, and from 20 to 80 cm. in depth. The bottom is sand and gravel with silt in the marginal areas of slower flow. The third area of the stream is very atypical and is a ditch which carries CSO from an outfall a distance of a half mile to Riley Creek. It has flow only when overflow occurs, is very rocky and unlike any other area of Riley Creek. CSO enters there and at Station 8.

The water quality data from the Agusut samples in Tables 6 and 7 characterize Riley Creek as a typical midwestern stream for its size and type. The values for BOD and DO are nominal with the exception of Station 9 in the August study. This station is at the headwaters of the stream and a small oil spill occurred there, probably effecting the values. The bacteriological data indicate no human-source organic enrichment. The data also indicate an effect downstream to the Station 10 site. The values for turbidity, nitrate and suspended solids indicate a possible effect from a landfill in operation between Stations 5 and 6. No CSO entry exits in that area. Only a slight elevation of FC/FS and total coliform values occur in the area where the CSO outfall is located, Station 8. The values from the October sampling also indicate normal conditions for Riley Creek (see Table 7). The effect of the greater volume of water present may influence some of the data. It should be noted that the October samples do not reflect any characteristics of first-flush CSO, if any were present, because the samples were taken after the several inches of rain by a period of several days. The data for Stations 11 and 12 show the stagnant, or nearly stagnant nature of that ditch. The August samples show low DO and elevated BOD, ammonia, turbidity, suspended solids, and phosphates. The bacteriological data also indicate human wastes. This is to be expected due to the CSO being the only source of flow in the ditch other than a minimal amount of surface runoff. The October samples were characterized by values possibly demonstrating the flushing effects of earlier CSO. In general, the water quality of Riley Creek is good over the part of the stream monitored and well within expected values for this type of stream.

The fish population sampled at the various stations on Riley Creek is rather average. The most diverse population occurs at Station 5 where the stream has several diverse communities. The populations of darters, shiners, minnows, and sunfish continue into the upstream stations. The populations are more heterogeneous than those of the Little Wabash. Only in the headwater area of Station 10, and to some extent just downstream at Station 9, are the populations diminshed in variety and numbers. The fish populations at Station 11 are spillovers from Station 9, the area of Riley Creek where the ditch which carries CSO flow enters the stream. The flow is only from surface runoff otherwise. The area of Station 12 is truly intermittent, and was dry with isolated pools during both samplings. Riley Creek appears to have a normal fish population for a small, improved, exposed, midwestern stream.

The benthic populations of Stations 5 through 9 on Riley Creek were diverse and contained those insect, snail, and worm forms that are expected in this type of stream. The worm populations are not large, and contain eight species in the system. The only exception to this pattern occurred at the headwaters stations, and the populations there were similar to the populations at the headwaters of Little Wabash. The worms were mostly L. hoffmeisteri, the population was not diverse. The October samples from Riley Creek show the seasonal aspects of benthos, with several types of insects decreased or not present. The worm populations tend to increase in size, however the species diversity was maintained. The samples from Stations 11 and 12 were characteristic of disturbed areas, primarily worms, with L. hoffmeisteri predominating.

The data indicate that Riley Creek is not adversely effected by the CSO it may receive at two different locations. The downstream areas below either entry are rather average in terms of water quality and biological communities. It appears that if first flush effects exist, they have no extended effect on the quality of the stream.

KICKAPOO CREEK

Kickapoo Creek is the only stream of the three studied that flows inside the city limits of Mattoon. Five of the stations, 18 through 23 are located in the city, with Station 23 at the headwaters, Station 21 located downstream of the Mattoon Water Treatment plant, and Station 18 immediately downstream of the Waste Treatment Plant. In the city, the stream is small, a meter or less in width, and 10 to 40 cm. in depth. The banks are steep and weeded without trees in some areas, and shaded in others. Homes, businesses and recreational areas border the stream. The stream is traversed by several streets. Outside of the city limits, the stream continues to be steep-banked and without shade for several miles and eventually widens to become a typical small midwestern stream, similar to Station 5 on Riley Creek. It has a well developed flood plain with mature trees, is several meters in width, varies from riffles to pools of a meter or more in depth, and flows through wooded areas as well as farms. There are scattered houses along this part of te stream, but for the most part it is isolated. It is crossed by occasional rural roads. Kickapoo Creek can be divided into the downstream-rural areas, Stations 13 through 15, a transitional area where Stations 16 and 17 are located, and the in-city stations, Station 18 through 23.

Table 10. Water Quality for Kickapoo Creek - August

	13	14	15	16	17	18
Dissolved Oxygen (mg/l)	6.80	6.20	5.70	2.50	3.70	6.20
Turbidity (NTU)	4.00	4.80	4.80	3.80	5.60	7.00
Suspended Solids (mg/l)	<1.00	8.70	6.70	2.00	5.30	19.00
Ammonia N (mg/l)	0.19	0.10	0.36	2.45	3.50	2.45
Nitrate (mg/l)	17.00	20.00	32.00	14.00	17.00	22.00
Ortho-Phosphate (mg/l)	1.30	1.45	1.20	.14	1.35	1.50
BOD (mg/l) 5.4	5.40	5.80	7.10	9.90	>15.20	>15.50
Fecal Coliform/Fecal Strep	0.33	0.16	0.28	3.91	3.43	1.19
Total Coliform/100 ml	3.0×10^3	7.0×10^3	7.0×10^3	$>2.0 \times 10^5$	$>2.0 \times 10^5$	$>2.0 \times 10^5$
Fecal Coliform/100 ml	5.9×10^2	2.8×10^2	3.6×10^2	8.6×10^4	1.8×10^5	1.8×10^5
Fecal Strep/100 ml	1.8×10^3	1.8×10^3	1.3×10^3	2.2×10^4	5.1×10^4	1.5×10^5
SPC/ml	7.3×10^4	1.2×10^5	4.8×10^4	1.0×10^5	3.8×10^5	5.6×10^5

	19	20	21	22	23
Dissolved Oxygen (mg/l)	4.20	4.00	5.70	5.40	7.20
Turbidity (NTU)	9.60	26.00	38.00	30.00	20.00
Suspended Solids (mg/l)	24.70	25.00	62.00	30.00	22.00
Ammonia N (mg/l)	0.58	0.44	0.40	0.54	0.11
Nitrate (mg/l)	9.00	10.00	11.00	11.00	19.00
Ortho-phosphate (mg/l)	0.12	0.06	0.07	0.11	0.11
BOD (mg/l)	8.80	6.80	8.00	7.70	4.70
Fecal Coliform/Fecal Strep	0.16	0.29	0.45	0.15	0.41
Total Coliform/100 ml	2.2×10^4	3.0×10^4	2.9×10^4	2.6×10^4	3.0×10^3
Fecal Coliform/100 ml	3.4×10^3	5.7×10^3	4.9×10^3	3.2×10^3	7.0×10^2
Fecal Strep/100 ml	2.1×10^4	2.0×10^4	1.1×10^4	2.2×10^4	1.7×10^3
SPC/ml	1.0×10^5	9.0×10^4	9.3×10^4	8.7×10^4	1.3×10^5

Table 11 Water Quality for Kickapoo Creek - October

	13	14	15	16	17	18
Dissolved Oxygen (mg/l)	11.70	11.40	11.40	10.10	11.00	9.90
Turbidity (NTU)	16.00	15.00	13.00	12.00	8.00	9.00
Suspended Solids (mg/l)	29.50	17.50	17.00	4.50	3.00	1.00
Ammonia N (mg/l)	0.20	0.36	0.38	0.19	0.12	0.39
Nitrate (mg/l)	33.00	35.00	39.00	36.00	29.00	26.00
Ortho-Phosphate (mg/l)	0.42	0.54	0.74	1.08	1.08	0.88
BOD (mg/l)	5.50	5.50	6.40	6.30	6.40	12.40
Fecal Coliform/Fecal Strep	0.67	1.44	0.90	1.00	not calc.	0.08
Total Coliform/100 ml	4.4×10^5	1.8×10^6	4.7×10^6	1.6×10^6	2.0×10^6	$>2.0 \times 10^7$
Fecal Coliform/100 ml	1.4×10^5	1.3×10^4	2.7×10^4	2.0×10^3	$<1.0 \times 10^3$	4.6×10^5
Fecal Strep/100 ml	2.1×10^4	9.0×10^3	3.0×10^4	2.0×10^3	$<1.0 \times 10^3$	5.6×10^6
SPC/ml	7.8×10^4	6.2×10^4	1.6×10^5	6.0×10^5	2.2×10^4	3.7×10^6

	19	20	21	22	23
Dissolved Oxygen (mg/l)	10.40	10.40	10.60	10.20	10.20
Turbidity (NTU)	10.00	10.00	9.00	9.00	6.00
Suspended Solids (mg/l)	3.00	2.50	5.50	6.00	3.60
Ammonia N (mg/l)	0.70	0.13	0.09	0.08	0.08
Nitrate (mg/l)	29.00	36.00	36.00	35.00	35.00
Ortho-phosphate (mg/l)	0.32	0.04	0.10	0.02	0.12
BOD (mg/l)	9.10	4.60	3.00	2.70	2.40
Fecal Coliform/Fecal Strep	0.06	>2.00	>1.00	>1.00	0.50
Total Coliform/100 ml	$<2.0 \times 10^7$	4.3×10^4	2.9×10^4	2.6×10^4	4.0×10^3
Fecal Coliform/100 ml	4.3×10^5	2.0×10^3	1.0×10^3	1.0×10^3	$<1.0 \times 10^3$
Fecal Strep/100 ml	7.0×10^6	$<1.0 \times 10^3$	$<1.0 \times 10^3$	1.0×10^4	2.0×10^3
SPC/ml	2.9×10^6	2.1×10^4	2.6×10^4	1.6×10^4	6.0×10^3

The water quality of the three downstream stations is quite average in the August samples. Value for the various tests are all within expected ranges. At Stations 16 and 17 however, DO, BOD, phosphate, and FC/FS ratios indicate enrichment, likley from a human source. At the time the samples were taken, a small fish kill had recently occurred in the area of Station 16. The BOD is also high at Station 18, just below the Sewage Treatment Plant, but is lower for the stations above the plant. Most of the parameters measured above the plant are nominal. The values for suspended solids and turbidity are higher than average. There are a number of possible sources for this elevation including homes, streets, gardens, the Water Treatment Plant, etc. No data was discovered to allow the source to be identified. The FC/FS ratios would tend to rule out material of human origin as the source.

The water quality determined from the October samples was different in several aspects from the August samples. In general, August DO values were higher over the entire stream. The values for turbidity were inverted when compared to the August samples, with the higher values downstream and the lower values upstream. Higher phosphate values were determined for the samples from Station 18 and stations downstream from it. The BOD remains high in the area of the Sewage Treatment Plant, but falls rapidly downstream from it. Nitrate levels are generally higher in that area as well, but the ammonia levels are lower. The nitrification process is one of the factors involved. While the values for BOD are lower in the system, the pattern, or relative nature of BOD per station, remains the same as in the August samples. In general, bacterial populations are higher in the October samples, but this is probably due to the temperature effects of survival in bacteria.

In general, the water quality data indicate that the stream is receiving an organic load, even in the dry periods when CSO may not be a contributing factor, and recovers from the effects of the organic load in a relatively short distance of stream flow. The downstream areas in particular are typical for a stream of this type. The area of the stream in the city is subject to a variety of possible sources of material, and could show a wide variety of effects.

The fish populations of Kickapoo Creek in the downstream areas are similar to Station 5 on Riley Creek, and average populations for small midwestern streams of this type, Table 12. The October samples for Station 13 indicate a few species not present, but the data for Station 14 show the same species are present in numbers similar to the August numbers. High water in the October period may have been a factor. The data also show the fish kill in the August data for Station 16. The fish taken in October at this station were of a single species. This area is bordered by several houses and a golf course and may be affected by local activities of the people in the area. Stations 17 and 18 had no fish present for either sampling period. Above these stations, fish collected in August were not collected in October at Stations 19 and 20. The most upstream stations, 21, 22, and 23 are shallow, narrow water areas where fish can move freely and avoidance is probably a major factor in distribution. For example, a school of fathead minnows were taken at Station 21 in the October sample producing numbers in the data not found in any other station. It is probably most significant that fish were taken in these areas, not necessarily the numbers taken.

Table 12. Fish Populations of Kickapoo Creek - August/October

	13	14	15	16	17	18
Silverjaw Minnow	81/20	6/79			No Fish	No Fish
Bluntnose Minnow	8/0	5/52				
Fathead Minnow	7/0	0/1				
Suckermouth Minnow	3/0					
Stoneroller		28/7	27/1			
Creek Chub		26/6	48/25	6/5		
Sand Shiner		6/1	5/19			
Redfin Shiner			2/0	1/0		
Steelcolor Shiner	0/1					
Stiped Shiner		5/0				
Orangethroat Darter	1/0	3/0	2/1			
Dusky Darter		1/0				
Spotted Bass	1/0					
Bluegill		28/0	44/0			
Green Sunfish		4/0				
Longear Sunfish						
Black Bullhead				*7/0		
White Sucker	2/0	12/0		*8/0		
Redhorse				*15/0		

	19	20	21	22	23
Bluntnose Minnow					0/1
Fathead Minnow	6/0	5/0	0/71	0/1	
Creek Chub	3/0		3/0	7/0	7/5
Bluegill			0/3		
Green Sunfish	5/9	2/0			
Longear Sunfish			0/1		

*Fish Kill August 4, 1982.

Table 13. Benthic Populations of Kickapoo Creek - August/October

	13	14	15	16	17	18
Oligochaeta						
Tubificidae	0/28	41/23	5/19	567/254	688/535	421/596
Lombriculidae					0/2	
Hirudinae				2/0		
Gastropoda						
Physa sp				1/2		0/1
Insecta						
Chironomidae	100/16	61/23	107/49	126/6	5/125	701/491
Ephemeroptera	5/0	1/0				
Simulidae	0/1			15/0		
Trichoptera		1/1				
Culicidae	0/1				1/0	
Coleoptera	3/1	0/1	2/0	1/0		
Odonata	3/0		1/0			
Decapoda						

	19	20	21	22	23
Oligochaeta					
Tubificidae	136/196	275/120	41/78	38/300	40/41
Hirudinae	4/6	10/7	12/9	14/16	
Gastropoda					
Physa sp	8/2	0/2	35/3	34/18	
Pelecypoda					
Sphaerium	43/11	1/6		0/3	
Insecta					
Chironomidae	90/37	14/23	56/16	18/17	14/14
Ephemeroptera			2/0		
Coleoptera			1/0		
Odonata	0/1			0/1	
Decapoda					
Cambarus			2/0		

The benthic populations samples from Stations 13, 14, and 15 are average for a normal stream. The insect populations are diverse and the worms are present in small diverse populations. The bottom material in these areas is sand and gravel. The October samples show the same type of seasonal variation in benthic organisms as previously mentioned for the data from Riley Creek. The benthic populations at Station 16 were worms, nearly all L. hoffmeisteri and a few chironomids. The worms persisted in the October samples and the number of chironomids fell. This mix is classically indicative of a disturbed area and usually organic enrichment is a contributing factor. The same type of community was found at Station 17, except that the number of worms is considerably greater. The bottom at Station 17 is soft silt, probably flocculant material from upstream settling out in this area of the stream. The drop in elevation is only 0.06Δ (ft/100ft) in this area of the stream, and settling is likely. Even after the rainfall in October, the conditions persist as do the populations of worms, and chironomids. This station is approximately a quarter of a mile downstream of the Sewage Treatment Plant.

Station 18 is approximately 50 meters below the outfall of the Mattoon Sewage Treatment Plant. The benthic community is similar to that of Station 17 except for numbers. Close examination of the worms in the two areas showed that several species occur at 18, but not at 17. The populations at 18 remained constant after a period of rain in the October samples. Stream conditions along the bank indicated that high-water conditions had occurred before samples were taken in August. The benthic populations at Station 19, 50 meters above the Sewage Treatment Plant, are different from those at 18. The worms are of several species, mollusks are present, and several leeches. This community composition holds pretty well for the remaining stations on the stream with some variations. The next station upstream, Station 20, is very similar in benthos composition. All of these stations are located in areas of the stream where the width of the water is a meter or less, and depth is 10 to 20 cm. The banks of the stream are steep and weeded and the stream is mostly exposed rather than being shaded. The bottom material is mostly sand and gravel, with occasional trash.

Station 21 is located at the entrance of several CSO sources. The stream has been widened in this area and the banks reinforced. A small flood plain is present, and indications are that large volumes of water enter the stream during overflow periods. This station is approximately one quarter of a mile above Station 20. The benthic population is similar to that of Station 20 except for small numbers. Station 22 is located just below the Mattoon Water Treatment Plant. The stream is quite narrow, and the bottom irregular with rocks and pieces of concrete. The population is mostly L. hoffmeisteri with only two other species present. Normal types of insects found on rocks were not present in this area. Station 23 is the headwaters station on Kickapoo Creek. The stream is formed from surface runoff, drainage tile from agricultural areas, and from cooling water (130,000 GPD) from a manufacturing facility in the immediate area. The most striking aspect of the benthos in this area is the variety of worms present. Six species were collected, several of which where not collected at any of the other stations on the three streams in the study.

The data from stations inside the City on Kickapoo Creek indicate that the stream is typical of small town drainage streams for the stations inside the city. The water quality and biological data suggest changing conditions and limited development. The entry of CSO in the area of Station 21 does not appear to have any direct or lasting effect on the immediate stream area. In the area of the Sewage Treatment Plant and extending downstream from it, a pollutant source is effecting the stream adversely. Water quality data and the biological communities samples indicate organic enrichment, probably of human origin. This effect extends from Station 18 through Station 16. Downstream of Station 16, the stream recovers rather quickly, and in the downstream areas as characterized by Stations 13 and 14, the recovery is complete. The stream in those areas is a typical type of stream with average water quality and normal biological communities.

SUMMARY

The three streams receiving CSO from the city of Mattoon apparently receive other effluents that make determining the exact effects of the CSO difficult. The Little Wabash and Kickapoo Creek are receiving organic enrichment, probably of human origin, during dry periods. Kickapoo Creek recovers after a stream flow of approximately 5 to 6 stream miles. Riley Creek shows no lasting effects of the CSO that may enter it at two locations. With the exception of a couple of local effects, it is a typical stream of its type for this area of the state. If relief from the factors effecting Little Wabash can be achieved, it is unlikely that CSO will be discovered to have a major effect on that stream's quality. In a similar case, relief of the material entering the Kickapoo, and perhaps attention to the problem of elevation in the areas of Stations 16, 17, and 18, would allow a study of the stream that would likely show that CSO is not a devastating factor to that stream.

A SCREENING METHOD FOR ASSESSMENT OF THE IMPACT OF NPS DERIVED DISCHARGES ON RECEIVING WATERS

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In order to make rational decisions regarding the planning, funding, and implementation of wastewater management programs on a community-wide basis, it is necessary to be able to assess the relative impacts of the various categories of wastewater discharges on the receiving water. The need for this type of assessment capability is threefold: (1) to determine the relative significance of the different categories of wastewater discharges in determining water quality, (2) to determine the order in which the various categories of wastewater should be subject to management based on the cost of the management and the benefits accruing to the receiving water, and (3) to determine whether or not the benefits obtainable from subjecting a particular category of wastewater discharge to management justifies the cost of the management.

Because of the extensive and historic body of knowledge and experience regarding the point source category of wastewater discharge, the assessment of the relative impact of these discharges, before and after treatment, on receiving waters is a relatively simple undertaking at all levels of planning and implementation. However, for the non-point source (NPS) and combined sewer overflow (CSO) categories of wastewater discharges there is no extensive and historic body of knowledge and experience that can be called on to support assessing the relative receiving water impacts of these types of discharges at any level of planning and implementation. In spite of the very considerable effort that has been expended on attempting to characterize the nature of the NPS processes and to predict and/or simulate those processes, the understanding of the generation and transport of NPS pollutants is still at the phenomenological level of understanding. Although extensive data collection, data analysis, and modeling efforts have been carried out, the parameters that determine NPS pollutant generation and transport, and the manner in which the parameters should be quantified have yet to be revealed. Thus, there have been basically two options for assessing the relative importance of NPS derived discharges in the context of a community-wide wastewater/water quality management program: (1) guess, or (2) spend reasonably large sums of money to collect and analyze data with no assurance as to whether or not the results of the data anaylsis are temporally transferable, let alone spatially transferable.

In so long as the bulk of wastewater management attention was focused on dealing with the gross aspects of point source discharges, the technological shortcoming of the NPS arena could be, and were, largely ignored. However, as the management of point source discharges reaches the level where each additional increase in management level incurs an exponentially increasing unit cost, and as it becomes increasingly apparent that NPS derived wastewater discharges are not going to be managed by precluding their discharges on receiving waters, the question of the impacts of such discharges on receiving waters and the cost of managing them becomes very important. Unfortunately, the technology comprising of NPS arena is not presently in a state that can be very effectively used to respond to such questions.

In appreciation of the above, a project was undertaken to design a technique to provide quantitive information at the most preliminary level of planning (most aggregate level of problem consideration) that could be used to assess whether or not the relative impacts of NPS derived discharges merit consideration in addressing wastewater/water quality management issues for any given community. The technique that was designed is referred to as a screening methodology because it provides an easy to use, inexpensive way to obtain a preliminary quantitative assessment of the relative impact of NPS derived discharge on receiving waters using a wide range of available data. The methodology, which supports the use of interactive graphics, and an example of its application to a combined sewer overflow are presented in this paper.

The methodology developed in this study utilizes statistical analysis of CSO data and simulation techniques in conjunction with interactive graphics to display the relative severity of impacts of the CSO upon the receiving stream. A major CSO in Columbus, Ohio discharging to the Scioto River was utilized in the development and testing of the methodology. One year of CSO discharge records and a long record of rainfall and stream flow were available for this area. The CSO discharge records and rainfall records were utilized to develop predictive equations for CSO discharge quantity/quality as a function of season and rainfall. The predictive equations were utilized in conjunction with the long rainfall record to generate a simulated CSO discharge record. A general purpose interactive graphics based computer program was developed to display the probability distribution of within stream pollutant concentrations with and without the CSO discharge. The user specifies a background stream concentration, characteristics of point sources discharging within the vicinity of the CSO, stream standards for the pollutant and normal or log normal probability axes. A severity index is calculated by the program as the difference in probabilities of an event of concentration greater than or equal to the allowable stream concentration with and without the presence of a CSO discharge. This index is considered a measure of the relative severity of the CSO. The analysis may be performed on a monthly, seasonal or total basis. Methods of applying the techniques developed in this study under varying degrees of data availability are described in the report. Situations that may be accommodated within this framework range from areas where only rainfall records are available to areas where complete and lengthy streamflow and CSO discharge records exist.

The methodology developed and demonstrated in this study proved to be an excellent means of measuring and displaying the impacts of CSO's urban runoff and other NPS derived discharges. The method can be applied under a wide range of data availability and this fact, in conjunction with the relatively low cost associated with the analysis, allows the technique to be used as a "screening" methodology for determining where further analysis should be preformed.

COMBINED SEWER OVERFLOW

AND

URBAN RUNOFF STUDY

IN

BELLEVILLE, ILLINOIS

by

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INTRODUCTION

The City of Belleville, Illinois has 60 miles of combined sewers and 40 overflow points serving an area of 4.5 square miles. The sewers were constructed at the beginning of the century and have been somewhat modified over the years. Dry-weather, sanitary flow is treated at the City's activated sludge wastewater treatment plant. During the wet-weather the normal carrying capacity of the existing combined sewer is exceeded. Overflows of mixed sewage and storm water from the combined sewers have been occurring nearly every time it rains. The result of an overflow can be significant discharge of organic material, nutrients, sediment, microorganisms, oil and grease, and metals and other potentially toxic substances into the receiving water. In most cases, concentrations are higher at the beginning of the overflow - the so-called first flush of material accumulated in the sewer.

FIRST FLUSH PROGRAM

In 1979, the City of Belleville decided to participate in the USEPA Construction Grant Program to comply with the current Illinois EPA Regulations and a Combined Sewer Overflow Monitoring Program. The purpose of the study was to determine the effect of the various rainfall events on the level of pollutant loadings to the nearby streams via overflow points. The impact of the combined sewer flow into the wastewater treatment plant and the number of back-ups into the residential basements were also studied. The combined sewer overflow monitoring program was also supported by Illinois EPA to re-emphasize on correcting the combined sewer overflow problems.

FIRST FLUSH PHENOMENON

Then prevailing Regulations of the Illinois EPA dictated that all rainfall related discharges from the overflow points with concentrations in excess of those expected on an average daily basis should receive the same degree of secondary treatment as the dry-weather flow.

The first flush phenomenon occurs in combined sewers because of the resuspension of the settleable pollutants in the sewer by the high flows during a significant rainfall event. Pollutant deposition takes place in the combined sewers because the average flow rates and velocities would not allow scouring during the low flow(dry-weather) conditions. With this point of view, the first flush then can be defined as the volume of wastewater which contains the large portion of the resuspended pollutants being flushed from a combined sewer plus pollutants from the surface runoff during the early stages of a significant rainfall event. First flush events and characteristics are unique and area-specific for every combined system.

STUDY OBJECTIVE AND PLAN

The primary objectives of the program were as follows:

1. Quantification of the actual flow rates as well as the concentration of the Biological Oxygen Demand, Suspended Solids and Fecal Coliform from the combined sewer overflows;

2. Partly or complete elimination of the first flush discharge of the combined sewer overflows to the nearby receiving streams;

3. Determination of the optimum first flush conveyance, detention and treatment facilities by more efficient use of the existing facilities and development of a feasible plan;

To achieve the established goals of the study, the existing conveyance system and appurtenances as well as the treatment facilities were evaluated. The drainage areas serving specific combined sewers were defined. Extensive meteorogical data was reviewed to determine the characteristics of a local first flush rainfall event which might be predicted. A field flow monitoring and sampling program was conducted to establish the first flush characteristics.

COMBINED SEWER OVERFLOW MONITORING

The combined sewers of Belleville represented highly complicated problems for a practical flow measurement and sampling. The following factors were unique and presented unusual field difficulties:

1. The presence of 40 overflow points and lift stations within the combined sewer service areas;

2. The existence of a variety of hydraulic and geometric overflow structures;

3. The coverage of 4 different watersheds within the combined sewer service areas;

4. The nonuniform distribution of historical meteorogical rainfall events over the combined sewer service areas;

5. The impact of the depressed (bowl-like) stormwater holding areas located within the upstream watershed;

6. The presence of the abandoned coal mine shafts beneath the ent~~ire~~ watershed;

A simple, economical, practical and feasible flow monitoring program could not be performed.

After an intensive research and field investigation the following information was obtained:

1. The previous study and reports related to the combined sewers, nearby stream investigations, infiltration/inflow analysis, 201 Facilities Plan, historical records of the sewer back-ups and meteorological data;

2. Preparation of the orthographic flow schematic of the combined sewers as well as the contributing lift stations to isolate the most critical overflow discharge points;

The analyses and the evaluation of the existing data and information helped to identify the relevant criteria to select a few representative overflow points and to find the overflow points which were physically and hydraulically suited for monitoring.

The concept of interpolating the characteristics of the selected points to virtually all of the unstudied areas to obtain a realistic and acceptable theoretical data was developed.

General criteria for choosing monitoring points included accessibility, type of structure, associated drainage area size, land use of the associated area, size of the sewers, population density, number of inlets from the street to the combined sewer and key points in combined sewer system. A field investigation was conducted to determine if the sites were accessible and physically suited for the monitoring equipment. More than half of the sites were found unsuitable, some because of accessibility or physicalproblems such as being situated in the middle of a heavily traveled street and others because of physical constraints relative to equipment installation.

FIELD MONITORING

Automatic flow metering and sampling equipment was installed at 6 representative locations to monitor the overflow volumes and pollutant levels. The installation of the flow meters required placing the bubbler tubes securely in the flow stream. A liquid level actuator was secured at the level of the site overflow which activated the sampler when the flow rose above its normal dry-weather depth. Wherever possible, the sampler intake tube strainer was mounted in such a way that it was out of the normal daily flowstream, yet, it would be in submerged condition when the overflow occurred. Upon activation, the automatic sampler collected a sample every 15 minutes for about 6 hours (24 samples).

Rainfalls were recorded by two-weighing buckets continuously recording rain gages. The raingages were installed at two separate locations. These gages recorded the total accumulation and duration of each rainfall. The intensity of each rainfall was calculated from this data.

The equipment was installed during the last two weeks of September 1980. A debugging period occurred after installation in order to get the equipment to operate properly. The equipment was serviced daily to keep the batteries freshly charged and to keep the equipment clean.

Collection of flow data was done based on a pre-determined timetable. Flow rate was computed and recorded by a project engineer and a hydrologic engineer.

Collection of wastewater samples and transportation to the appropriate lab facilities was under supervision of a project engineer.

Results from lab facilities were transmitted to the project engineer or sanitary engineer for interpretation and recording.

It was anticipated that during the winter months the only precipitation would be in the form of snow and not appropriate to the study. Therefore, the monitoring program was suspended for the winter months at the end of November 1980 and the equipment was removed. The program was resumed during the second week of March 1981 and continued through the end of May 1981 at which time the data collection portion of the project was completed.

The principal parameters measured during the field monitoring were flows (Q), Biochemical Oxygen Demand (BOD), Suspended Solids (SS) and occasional Fecal Coliform.

DATA ANALYSIS

The operating data of the wastewater treatment plant between June 1980 and May 1981 were analysed to establish base flow and parameters. The 3 month dry-weather averages were:

Flow --------------- 4.71 MGD

BOD --------------- 241 mg/L

S S --------------- 471 mg/L

Lb BOD/Day -------- 9,400 #/day

Lb S S/Day -------- 18,800 #/day

The term "Base Flow" includes the average daily flow generated by domestic and industrial customers plus a quantity of dry-weather (minimum) infiltration.

A rainfall intensity of 0.3 inches per hour was determined to be a first flush rainfall event for the City of Belleville's combined sewers and can be expected to occur once any given year.

During the course of the monitoring program, three significant first flush rainfall events occurred. First flush rainfall events occurred on October 17, 1980, April 3, 1981 and May 18, 1981. Each of the three rainfall events chosen as first flush rainfalls met the criteria for choosing a first flush rainfall event as outlined in the "Procedures for Determining Compliance with Rule 602 (c)."

The availabe data indicated that the first flush was evident in Belleville's overflow points. The existing combined sewer system exhibits a first flush in the overflow volumes discharging from the system. Three of the six monitored flow measuring and sampling sites produced significant overflow volumes during a first flush rainfall event. The largest first flush overflow volume was approximately 500,000 gallons. The interpolation of this volume to similar overflow locations with the established parameters helped in the determination of total first flush overflow volume within the combined sewer areas.

Therefore, 13,500,000 gallons is now considered to be the first flush volume for the City of Belleville.

FIRST FLUSH TREATMENT QUANTITIES

The current treatment requirements are established by the use of the concept of "Organic Population Equivalent" -"O.P.E." method. The total O.P.E. was calculated by the total amount of BOD and the SS present in the combined sewer system. The O.P.E. for this study was established as 94,000.

Illinois EPA regulations outlines the requirements for the combined sewer system overflows. New combined sewers are prohibited and the existing combined sewer systems shall convey the maximum amount of combined flow to the treatment facilities. All system bypasses and overflows that are not absolutely necessary shall be eliminated, or alternate facilities will be provided for sufficient treatment to insure the removal of floating and the settleable solids and final disinfection. Raw sewage overflow, including peaks and first flush from combined sewers, shall receive treatment.

The O.P.E. obtained from the study was multiplied by 1,250 gal/P.E./day (10 times dry-weather flow plus dry-weather flow adjusted for maximum diurnal peaks) generated a flow rate of 117.5 MGD which requires some level of treatment.

DEVELOPMENT OF ALTERNATIVES

Based upon the general characteristics of the combined sewer system, topography, field investigation and study findings, the following alternatives were developed:

1. NO ACTION;

2. STORM SEWER SEPARATION:

3. PEAK FLOW STORAGE:

4. SPO~~T RE~~DUCTION OF OVERFLOW CONCENTRATION;

5. OVERFLOW SURCHARGE RELIEF INTERCEPTOR;

6. BOTTLE NECK ELIMINATION;

7. INSTALLMENT OF FIRST FLUSH REGULATORS:

8. SPOT SEWER SEPARATION

9. ON-SITE DOMESTIC SEWAGE RETENTION;

All of the above alternatives were considered in a feasibility analysis for a final selection.

RECOMMENDED ALTERNATIVES

Due to the existence of the higher degree of complicated combined sewer system in Belleville, no one single solution but a combination of alternatives were selected. The recommendations were as follows:

1. Construct Three Surcharge Relief Interceptors: Three surcharge relief interceptors along the concentrated overflow points to receive the first flush event and convey it to the holding basin;

2. Holding Basin: A total volume of 25 million Gallon capacity with a surface area of 7.5 acres and surface aeration;

3. Construct Multi-Level Regulators: Connection of the existing overflow points as a separate group into a single multilevel regulator in intercept the first flush but release the excess flow into the nearby creek;

4. Install Swirl Regulators: Serve the isolated overflow areas which cannot be grouped together by installing individual swirl regulators;

5. Eliminate Bottle Necks: Replacement of larger size pipes in a telescopic fashion in the existing main interceptor to eliminate the smaller size pipes in downstream areas;

6. Reduce Stormwater Inlet Size: Delay of the stormwater entering into the combined sewers by making smaller entrances into the inlets;

7. Separate Storm Sewers: Construction of separate storm sewers in 3 separate bowl-shaped depressed areas along the existing

main interceptor to prevent the concentrated storm flow into the combined system.

Over and above the recommended structural alternatives, the City of Belleville decided to follow severalother stormwater control programs. Among those, periodic street cleaning procedures, enforcement of the street cleaning ordinance, regular sewer flushing and catch basin cleaning and elimination of down spout connection within the City.

CONCLUSIONS

The City of Belleville is the owner of an old sewer system which was built at the beginning of this century. The City accepts these archaic sewers like old debts and have been carrying over 70 years.

During the course of the first flush study, the City has learned how complicated the combined sewer system works.

There are overflow discharges from the system almost every time it rains. However, there has not been any serious impact in the receiving nearby streams. The laboratory analysis of the first flush samples somewhat confirmed the minimal pollutant discharge from the system.

A complete separation of the system is considered ideal but cost-prohibitive. The City agrees to implement a feasible first flush conveyance plan with the help from the construction grants program.

At present the City is participating in "Exception Procedures" developed by the Illinois EPA to implement a site-specific solution to Combined Sewer Overflow problems rather than a complete pollution prevention program.

SESSION 2-B: URBAN EFFECTS ON SEDIMENT

Urban Runoff Impacts on an Agricultural Receiving Stream: Champaign, Illinois NURP

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INTRODUCTION

One of the goals of the U. S. Environmental Protection Agency's Nationwide Urban Runoff Program (NURP) was the evaluation of impacts of urban storm runoff on receiving waters [1]. From September 1981 to March 1983 a project addressing this goal was carried out by the Illinois State Water Survey (ISWS) for the Illinois Environmental Protection Agency (IEPA) as part of IEPA's NURP efforts [2]. Both IEPA and ISWS had been involved in a prior NURP project to evaluate municipal street sweeping as a management practice for control of urban stormwater quality [3]. The assessment of urban runoff impact was based principally on results of monitoring water quality in an urban creek and its agricultural receiving stream during storms and dry weather from October 1981 to September 1982. The data collection program included other elements aimed at identifying general characteristics of the streams. These efforts enabled the assessment of existing physical, chemical, and biological conditions in the streams and enhanced the transferability of the results to other locations. This paper is concerned mainly with interpretation of stream water quality results.

PROJECT DESIGN

Champaign-Urbana, Illinois was the study area for the project (figure 1). Five sites were instrumented for rainfall and streamflow quantity and quality monitoring. Sites 2 and 3 were located on Boneyard Creek, an urban stream which drains 5.7 square miles of separately sewered urban area, including the central business districts of both Champaign and Urbana. The average daily flow in the creek is 4 cubic feet per second (cfs). The remaining three sites were located on the Saline Branch of the Vermilion River, an agricultural drainage ditch which receives the flow from the Boneyard inside Urbana city limits. Site 1 was placed upstream from any contribution from Champaign-Urbana, at a point where the drainage area of the stream is 51 square miles of agricultural property, mostly tilled fields planted in row crops. Daily flow at site 1 averaged 5 cfs. Site 4 was placed at a point 0.3 mile downstream from the confluence of the streams and 0.2 mile upstream from the outfall of the Urbana-Champaign Sanitary District's northeast sewage treatment plant. Site 5 was located at a point 3.8 miles downstream from the treatment plant outfall, defining the boundary of the study area. The drainage area at site 5 was 74 square miles

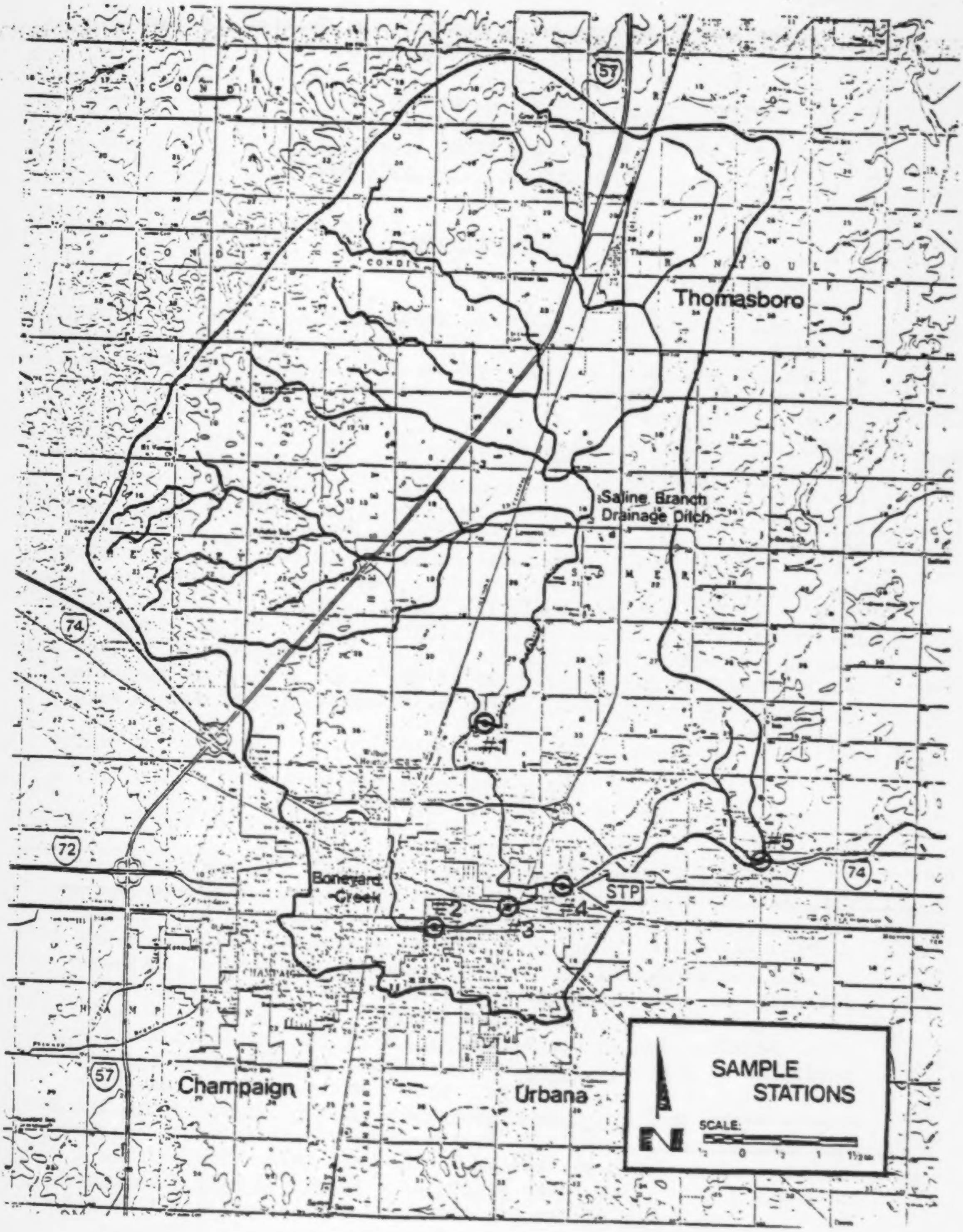
Thomasboro
Saline Branch
Drainage Ditch
57
74
72
#1
#2
#3
#4
#5
STP
Boneyard
Creek
Champaign
Urbana
SAMPLE
STATIONS
SCALE
N

Figure 1. Champaign-Urbana NURP project study area

and the average daily flow was 45 cfs, of which 20 cfs was effluent from the sewage treatment plant.

A computer-controlled telemetry system was installed for collection, storage, and management of runoff event data. Water level sensors and automatic flow samplers were placed at all five sites. Stage-discharge relationships were supplied by the U. S. Geological Survey for two sites and determined by ISWS for the other three sites. Three rain gauges and one wet-dry fallout sampler were also used in the equipment network. During storms, rainfall and flow data from the sites were recorded at one-minute intervals. Discrete samples for water quality analyses were ordered throughout the events at intervals which varied by site from 5 to 30 minutes. Laboratory determinations of concentrations of a broad list of constituents, including solids, metals, and nutrients were made on the runoff and rainfall samples. Two constituents, lead and ammonia-nitrogen, will be highlighted in this paper. Altogether, 31 events were monitored and sampled during the data collection period.

RESULTS

Figures 2 and 3 display typical results from the event data collection program. The event represented in the figures occurred in the afternoon of June 28, 1982. Rainfall totals for the event were 0.20 inch at site 1, 0.98 inch at site 2, and 0.55 inch at site 4, indicating that the storm was localized over the urban area. The one-minute flow records for the six-hour period following the start of the storm are plotted for sites 1, 3, and 5 in figure 2 and for sites 2 and 4 in figure 3. The total lead concentrations in milligrams per liter (mg/L) of discrete samples taken at each site and analyzed for metals are plotted in positions corresponding to sampling times. Similar plots were drawn for other constituents analyzed in this event and for all analyzed constituents in other monitored events.

Table 1 contains values calculated and observed from the site records of the June 28 event. Runoff characteristics include peak and mean discharge in cfs and total volume in cubic feet (cu ft). Water quality characteristics for lead include observed peak concentration and event mean concentration (EMC) in mg/L and event washoff load in kilograms (kg). The EMC is the flow-weighted average concentration of the constituent for the entire event at the site and is calculated from the discharge record and the results of discrete sampling. Throughout NURP, the EMC was used as the definitive water quality characteristic of the event record at a runoff-monitoring site. The washoff load is the product of runoff volume and EMC.

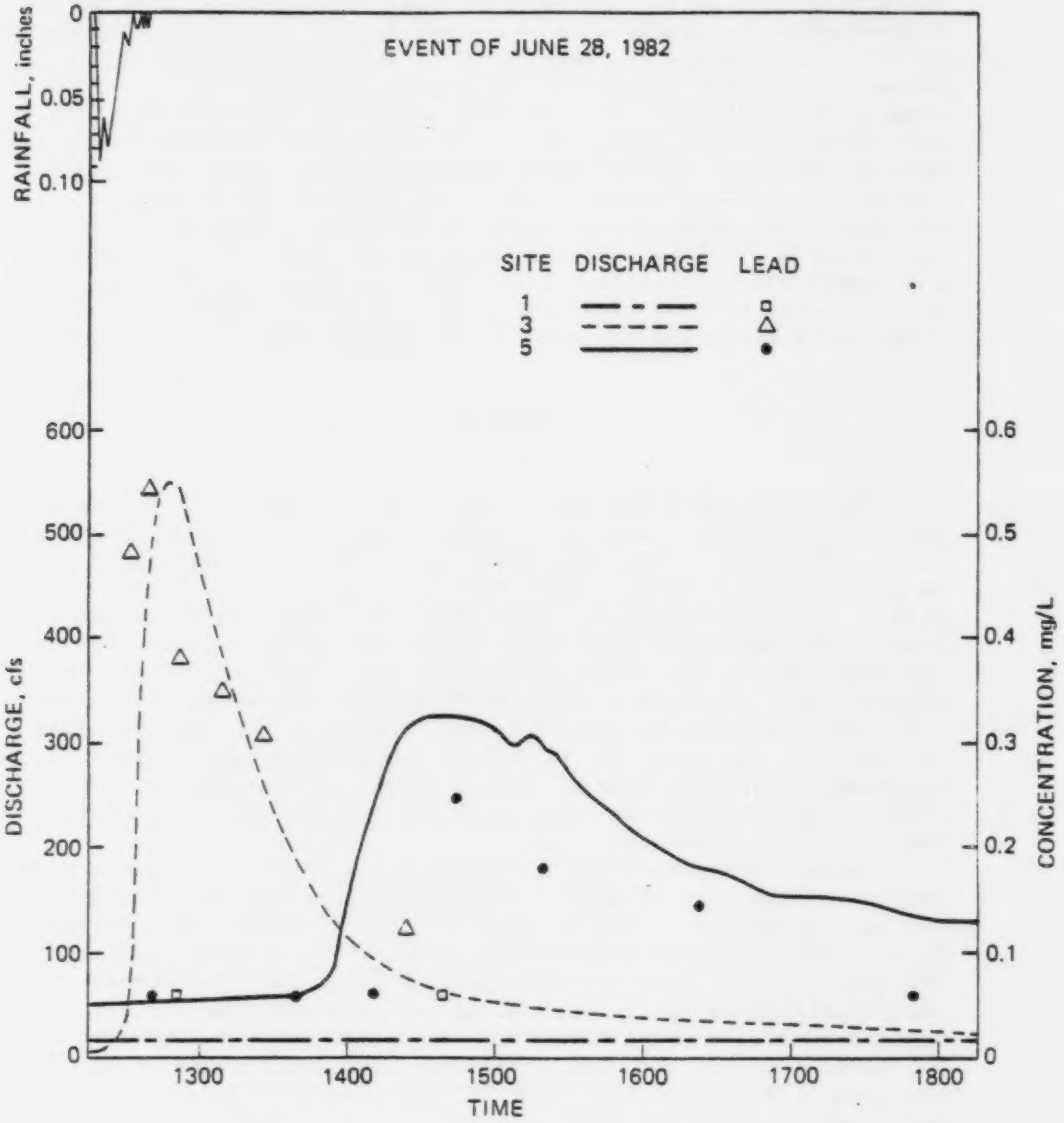

Figure 2. Event data for June 28, 1982 at sites 1, 3, and 5

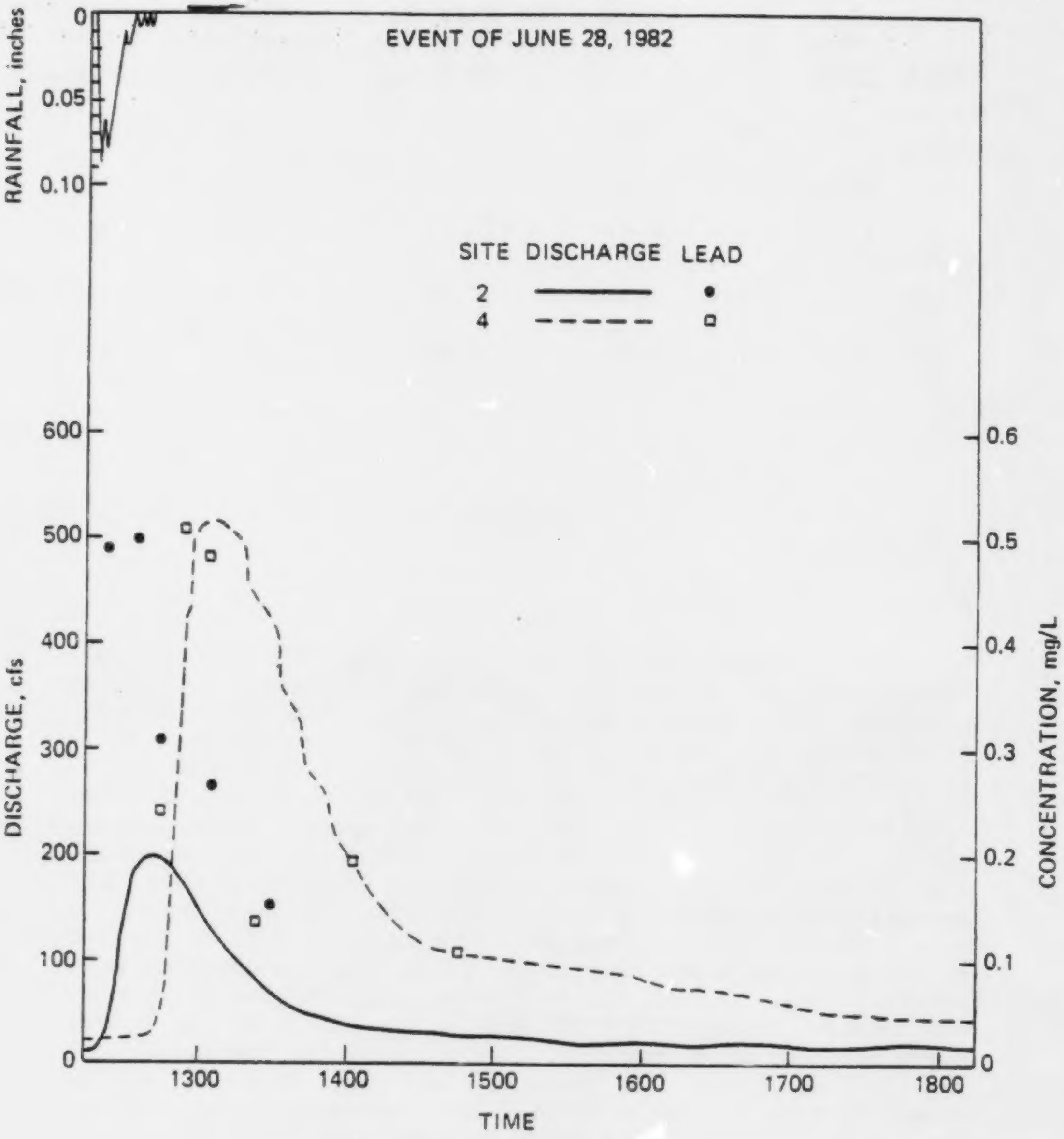

Figure 3. Event data for June 28, 1982 at sites 2 and 4

Table 1. Event Characteristics by Site for the Event of June 28, 1982

Site	P~~eak~~ Flow (cfs)	Mean Flow (cfs)	Runoff Volume 1000 (cu ft)	Observed Peak Concentration (mg/L)	Event Mean Concentration (mg/L)	Event Washoff Load (kg)
1	17.1	17.1	280	.05	.05	0.4
2	194.8	41.5	868	0.50	0.27	6.6
3	553.2	102.7	2168	0.54	0.33	20.2
4	512.5	127.9	2455	0.51	0.26	18.1
5	345.3	164.5	3413	0.25	0.14	13.5

ANALYSIS

SITE VS. SITE ANALYSIS

For each site, EMCs and loads were calculated for sampled constituents in all monitored events and the results analyzed in two ways. For single constituents, individual plots of EMCs or loads at one site against those at another site were produced, featuring all events for which there were data at both sites. Plots for lead and ammonia-nitrogen EMCs for three site pairings constitute figure 4. The upper two plots compare results between sites 1 and 3. The lower four plots contain similar comparisons from sites 3 and 4 to those from site 5. It is clear that the average concentrations of both constituents were much greater at site 3 than at site 1. This is attributable in part to the lack of any appreciable response to the storm from the upstream agricultural area. Indeed, figure 2 shows that the flow at site 1 was constant through the event and that no flow response to the storm occurred there before the urban runoff had passed out of the observed system. The remaining lead plots show that average concentrations of lead at sites 3 and 4 exceeded those at site 5, suggesting dilution of the urban load by other flows or loss of suspended material through sedimentation. Meanwhile the average concentrations of ammonia-nitrogen were greater at site 5 than at either site 3 or site 4, indicating an additional source of the constituent (the sewage treatment plant effluent) between sites 4 and 5. The inclusion of the general use water quality standards in the plots permitted the observation that EMCs of lead exceeded standards occasionally at site 5, frequently at site 4, and always at site 3, while EMCs of ammonia-nitrogen exceeded standards only at site 5 for about half of the events.

Figure 5 contains the site vs. site plots of event loads of

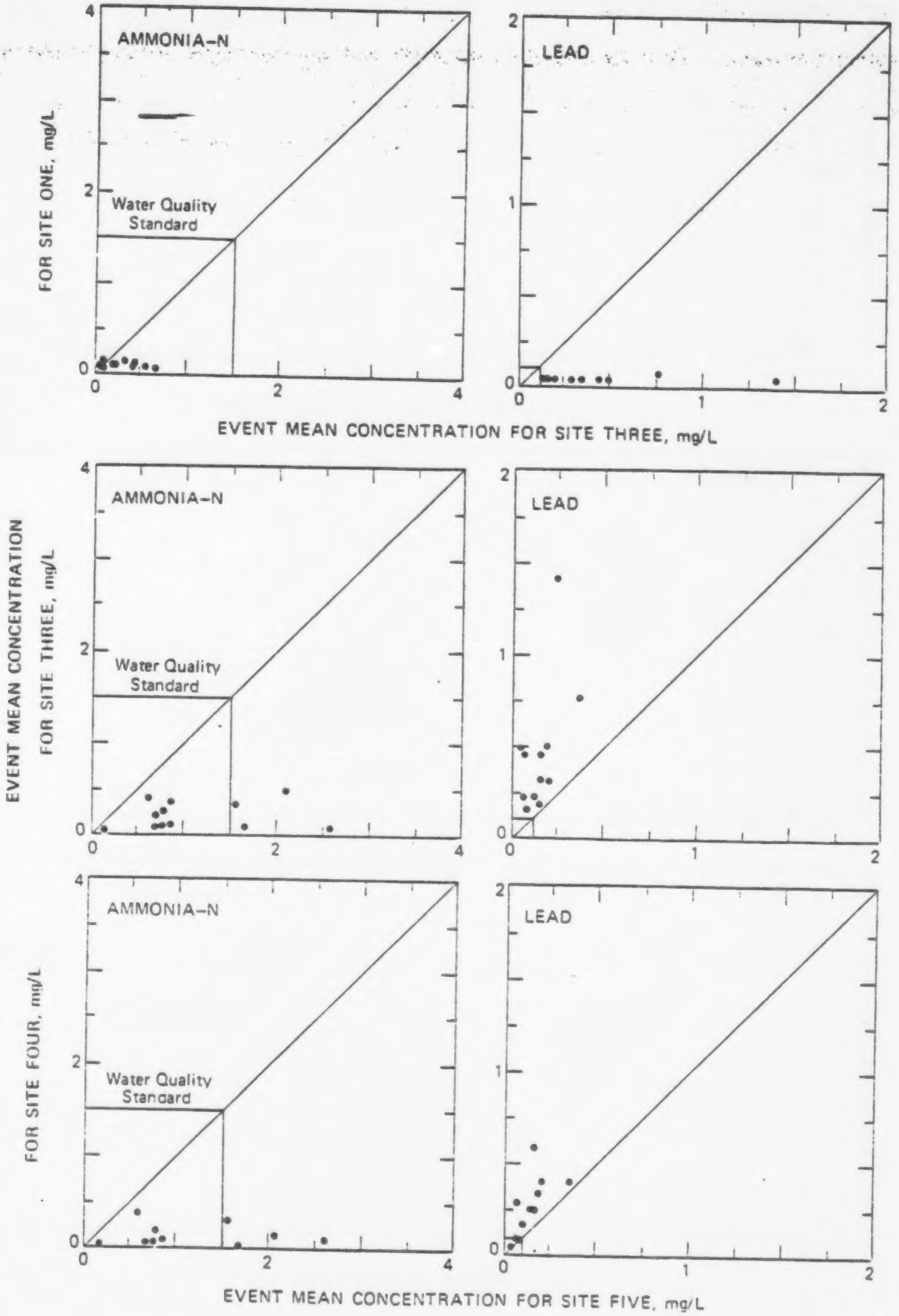

Figure 4. Site vs. site plots of EMCs of lead and ammonia-nitrogen

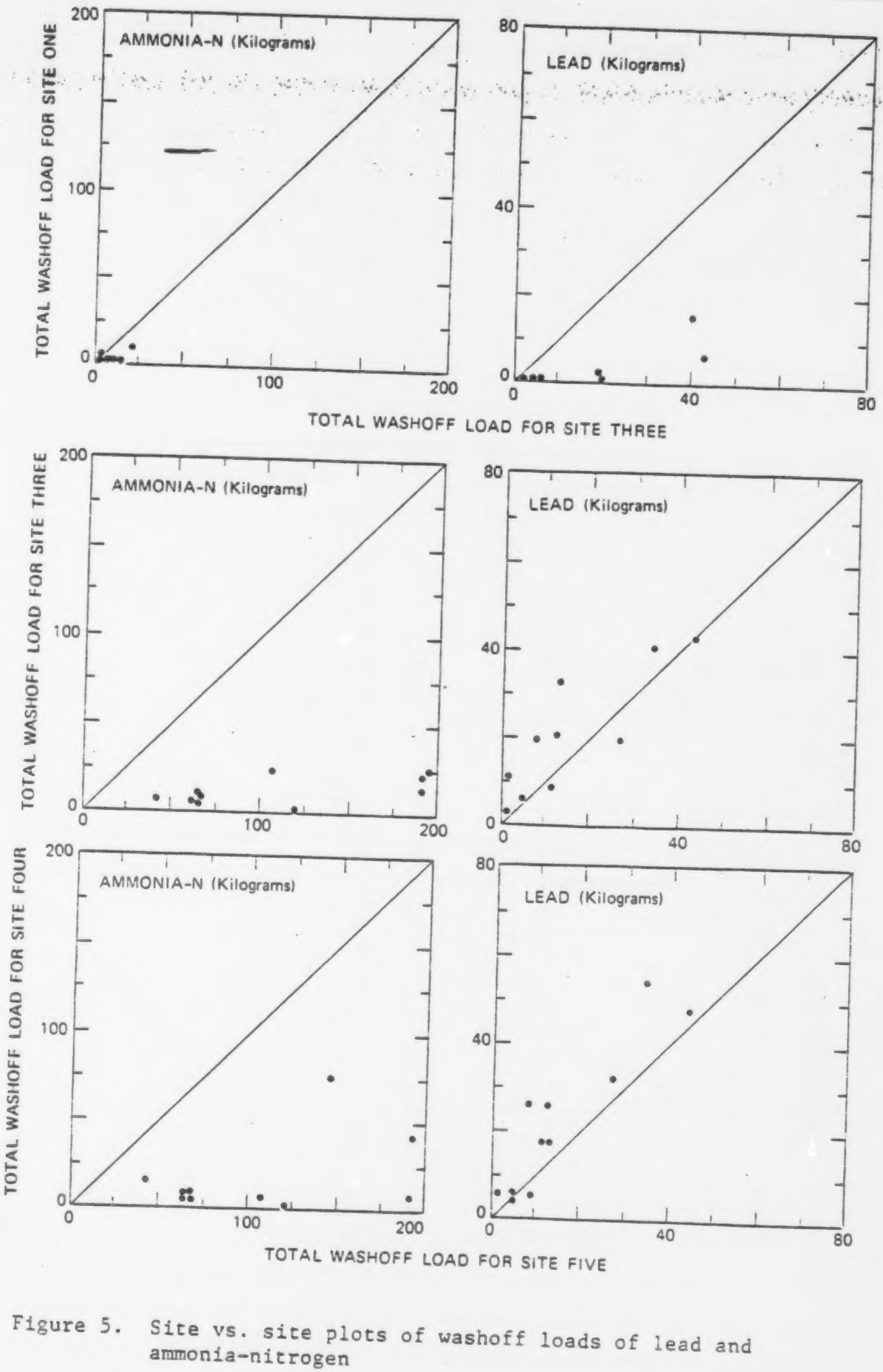

Figure 5. Site vs. site plots of washoff loads of lead and ammonia-nitrogen

ammonia-nitrogen and lead which correspond to the plots of EMCs in figure 4. Inspection of the lead plots shows that dilution alone cannot account wholly for the difference in EMCs between sites 3 and 5, since the loads at site 5 were still less than those at site 3. Deposition of some lead-bearing solids must have occurred. The ammonia-nitrogen plots confirm that the greatest part of that load at site 5 enters the stream below site 4.

LOG-NORMAL ANALYSIS

A form of data analysis different from the comparison of results from individual sites for single events involved the use of all data obtained at a site to identify characteristic response to storms. Both USEPA's evaluations of the entire NURP data base and ISWS's investigations of its full records at each site showed that the log-normal distribution was most descriptive of the data. For each constituent monitored, the EMC or load data for all events at one site were fitted to a log-normal distribution and the resulting line was plotted with its 90 percent confidence band. Figures with these features were drawn for every site and compared to each other to provide the basis for this analysis. Table 2 contains characteristics of the log-normal distributions of EMCs and loads of lead and ammonia-nitrogen at sites 1, 3, 4, and 5. The tabulated entries presented for each constituent and site include the median (and mean) of the log-normal distribution and the values of the upper and lower 95 percent confidence interval at the log-normal median. In the log-normal distribution the median and mean are coincident. This value was selected for use in comparing distributions because it represents the 50 percent exceedence probability; that is, it is the value for which the chances are exactly even that the EMC or load of the constituent during an event will or will not exceed it. Figures 6 and 7 contain individual plots for EMC and load of lead and ammonia-nitrogen, with each plot consisting of the log-normal distributions for sites 1, 3, 4, and 5.

Examination of the EMC information in table 2 and figure 6 reveals that lead levels were highest at site 3 and progressively lower in the downstream direction. The differences between the median values at sites 3 and 4 and sites 4 and 5 were statistically significant. The medians at all three sites exceeded general use water quality standards. The levels reported for site 1 are artificially high because conservatively high estimates of lead concentration for samples with actual concentrations below detection limits were used in EMC calculation. The ammonia-nitrogen levels at site 3 were elevated significantly above those at site 1 and were only moderately diluted by the receiving stream at site 4. However, the levels at site 5 vastly exceeded those at all other sites. Even then, the median there was still below the water quality standard. The load information in table 2 and figure 7 confirm the findings of the earlier analysis for ammonia-nitrogen; that is, some load at site 5 in the receiving stream is from urban runoff, but the greatest part enters below site 4 in the sewage treatment plant effluent. However, the results of this analysis

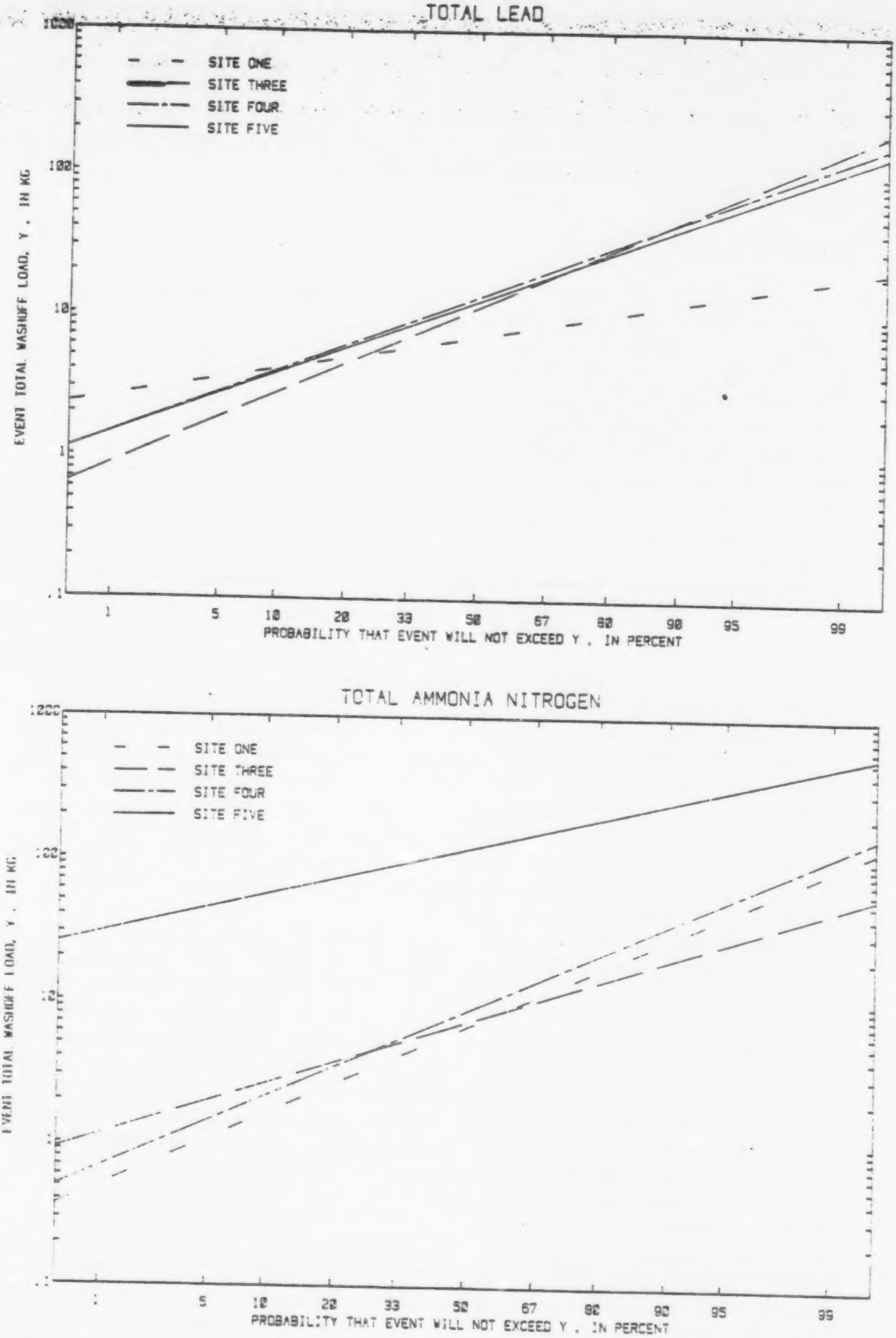

Figure 7. Log-normal distributions of loads of lead and ammonia-nitrogen

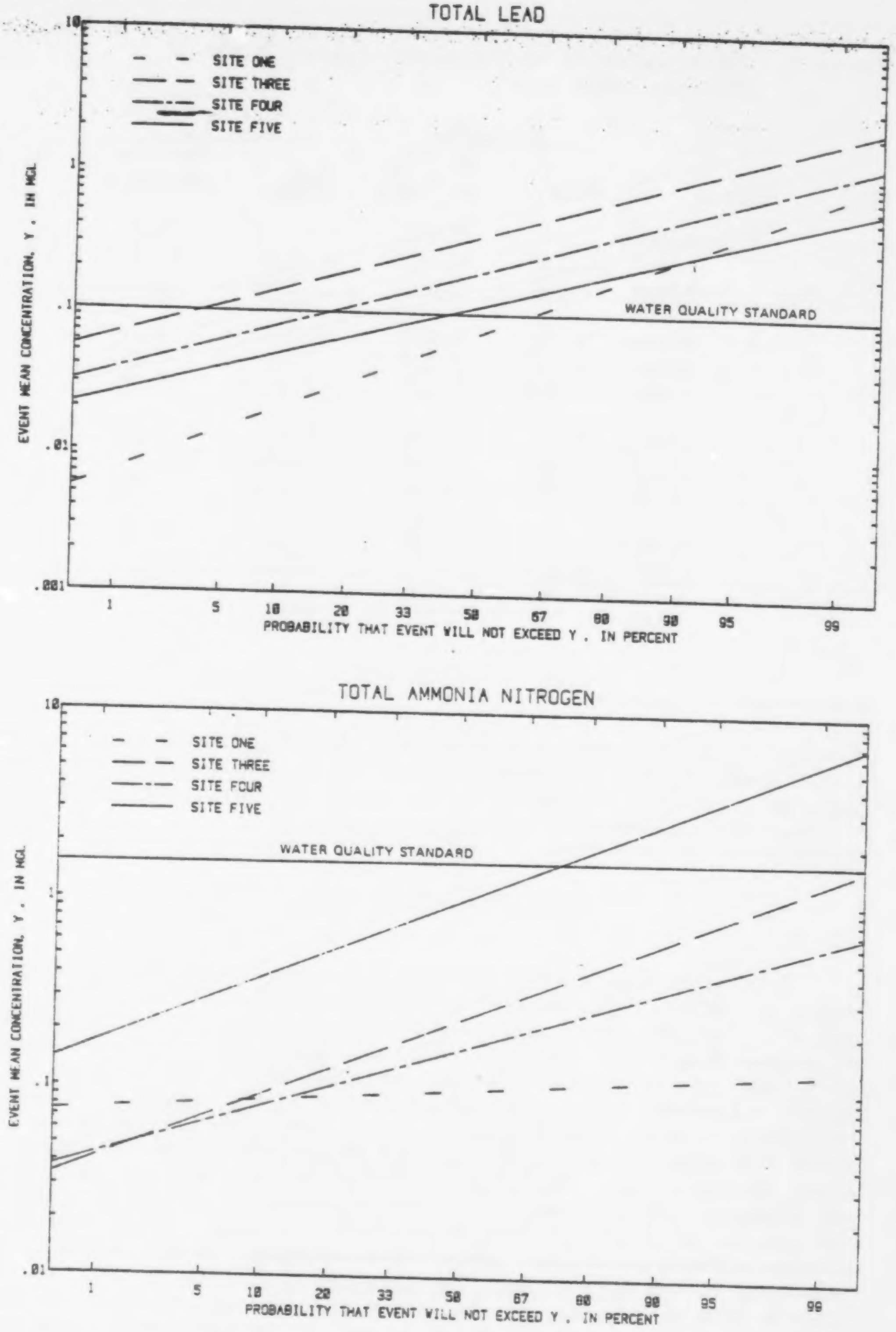

Figure 6. Log-normal distributions of EMCs of lead and ammonia-nitrogen

Table 2. Characteristics of Log-Normal Distributions of EMCs and Loads

		EMC(mg/L)		Load(kg)	
Site		Lead	Ammonia-Nitrogen	Lead	Ammonia-Nitrogen
1	median	0.071	0.098	7.09	6.64
	upper	0.115	0.103	9.99	16.2
	lower	0.044	0.093	5.04	2.72
3	median	0.349	0.232	11.4	7.21
	upper	0.460	0.308	17.6	9.82
	lower	0.265	0.174	7.44	5.30
4	median	0.194	0.161	13.6	8.63
	upper	0.278	0.214	22.6	15.0
	lower	0.136	0.121	8.16	4.95
5	median	0.112	0.991	12.6	118.
	upper	0.155	1.45	20.2	159.
	lower	0.081	0.678	7.89	87.7

for lead loads indicate that there are no statistically significant differences between the loads at sites 3, 4, and 5, suggesting that dilution more than deposition is the cause of lower lead concentrations in the receiving stream.

DISCUSSION AND CONCLUSIONS

This paper has featured results for two constituents, lead and ammonia-nitrogen. Ten others were given equal attention: total suspended solids, total dissolved solids, sulfate, chloride, nitrate-nitrogen, phosphorus, total Kjeldahl nitrogen, chemical oxygen demand, iron, and copper. Copper behaved very much as did lead, though it showed relatively higher background levels in the receiving stream. Phosphorus behaved almost identically to ammonia-nitrogen, since there are large soluble quantities of phosphorus in the treatment plant effluent also. For iron, suspended solids, Kjeldahl nitrogen, and chemical oxygen demand the levels observed in the urban stream and the receiving stream were essentially the same. For dissolved solids, chloride, sulfate, and nitrate-nitrogen, levels in the receiving stream were higher than those in the urban runoff. It appears from the results of this study that the major effect of the urban stormwater on the receiving stream is the temporary elevation of constituent concentrations, especially those which can be associated with the large suspended load in urban runoff. The receiving stream shows resilience in returning to pre-storm levels of these constituents shortly after the conclusion of the event.

Principal conclusions of the study were the following:

1. The primary water quality impact of urban runoff from Boneyard Creek on the Saline Branch receiving stream is the elevation of stream concentrations of lead, copper, and iron to levels 5-10 times background concentrations and well above water quality standards. For these constituents the probability range is 85-100 percent that event mean concentrations for an event will exceed standards in the Saline just downstream from the Boneyard. For total suspended solids, phosphorus, Kjeldahl nitrogen, and chemical oxygen demand, median EMCs in the Saline due to urban runoff range from 4 to 16 times routine background levels.

2. The elevated concentrations of the above-named constituents in the Saline have short durations, generally no more than two to three hours beyond the end of a rainstorm. Also, 30 percent of the Kjeldahl nitrogen, 60 percent of the phosphorus, 70 percent of the copper, and virtually 100 percent of the lead and iron are associated with suspended solids.

3. The effluent from the sewage treatment plant has greater influence on receiving stream levels of phosphorus and ammonia-nitrogen than has the urban stream, in storms as well as in dry weather. About 91 percent of the load of ammonia-nitrogen to the Saline during the year of monitoring was attributable to the treatment plant effluent.

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CHEMICAL ANALYSIS OF SURFICIAL SEDIMENT FROM ILLINOIS STREAMS

by

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Introduction

SEDIMENT IN STREAMS

Many toxic substances and contaminants of interest to persons concerned with pollution abatement sorb to particulates carried by water. Although heavy metals, nutrients, and oxygen demanding materials are naturally occurring sediment constituents, elevated levels can generally be attributed directly or indirectly to man. Pesticides, on the other hand, are not naturally occurring substances, and their detection attests directly to man's influence in the watershed.

Sediment analysis is particularly useful as a screening device to detect and identify contaminants periodically released from a point source that are not readily detected by routine water quality sampling. Sediment has additional advantages because it is generally universally available and may be collected when toxic contaminant levels have eliminated bio-accumulators such as fish. Collection and chemical analysis of stream sediments is thus a useful monitoring tool to document the extent of man's influence on the aquatic environment. It can be used to locate potentially harmful loadings, target areas where further monitoring is appropriate and identify areas where remedial actions are necessary.

IEPA SEDIMENT MONITORING

Since 1974, the Illinois Environmental Protection Agency (IEPA) has routinely collected stream sediments and more recently, lake sediments, for monitoring purposes. Results of sediment analyses for samples taken from 63 Illinois lakes in 1979 were evaluated in a single report [1]. An "in house" report [2] documented results of the 1974 stream sampling and summarized analyses of 140 samples for selected heavy metals, nitrogen, phosphorus, COD and volatile matter.

IEPA field personnel have taken stream sediment samples in conjunction with intensive stream studies at sites throughout the state. By the end of 1980, sediment samples had been collected from over 550 sites. Analytical results have been published in various Agency reports; these sediment data were generally used to substantiate results of associated water quality and/or macro~~inver~~tebrate collections. No attempts, however, had been made to analyze stream sediment data on a statewide basis.

For sediment analyses to achieve maximum utility in data interpretation, trend analysis and toxic detection in ongoing monitoring programs, it was necessary to analyze all available sediment data to establish background levels. It was also important that existing data be evaluated to describe sediment chemistry characteristics resulting from differences in watershed, geography and point source discharges. This report provides a brief summary of sampling methodology, data handling procedures, discussion of findings relative to selected sediment constituents, and finally, a classification of stream sediments from a more comprehensive 1983 IEPA report [3].

Methods

DATA COLLECTION

Collection of sediment samples was accomplished by IEPA staff operating out of regional offices in Marion, Maywood and Springfield, Illinois. Where wading was possible, sediment was collected using a brass sieve or polyethylene scoop. In deeper reaches a petite Ponar was used. Because sediment deposition does not occur equally across the stream profile, field personnel sought out areas of reduced flow for deposits of fine texture characteristically high in fine organic, clay and silt material.

In 1974 samples were placed in "whirl pack" bags. In subsequent years, sediment samples analyzed for heavy metals, nutrients and chemical oxygen demand (COD) were placed in polyethylene containers; samples for organic analysis (e.g., PCBs, DDT, dieldrin, etc.) were placed in acid washed glass bottles with foil or teflon lined caps. Samples were transported frozen to the appropriate IEPA lab for analysis. Organic pesticides and PCB analyses were performed at the IEPA laboratory in Springfield; remaining analyses were performed at the Agency's Champaign facility. All analyses were performed according to accepted USEPA procedures (Table 1).

DATA HANDLING AND ANALYSIS

Data were stored in the USEPA STORET data base system and statistical analyses performed using SAS [18]. Data were analyzed to establish background levels and to determine sediment chemistry characteristics at locations impacted by various point and non-point discharges and at varying distances downstream of municipal wastewater treatment facilities. To accomplish data analysis by pollutional source and stream distance, the location of each site with respect to upstream pollutional sources and distances between sites and upstream discharges were determined. When sites were located

TABLE 1. Summary of monitored parameters, sample preservation, methods of analysis and reporting units for Illinois Stream Sediments monitored.

Parameter	Sample Container	Preservation	Method of Analysis	Units of Measurement	Lab Performing Analysis
Total Kjeldahl-N*	8 oz. Polyethylene	Freezing	Digestion at 370°C using reagent containing mercuric oxide, potassium sulfate, and H_2SO_4 to convert organic nitrogen to ammonia. Determination of ammonia nitrogen by Phenate Method using Techicon AutoAnalyzer.	mg/kg N	Champaign IEPA Lab
Total Phosphorus-P* (TP)	8 oz. Polyethylene	Freezing	Digestion using H_2SO_4 and ammonium persulfate to convert all phosphorus forms to orthophosphate followed by determination using Ascorbic Acid Reduction Method and Technicon Auto-Analyzer.	mg/kg P	Champaign IEPA Lab
Chemical Oxygen Demand* (COD)	8 oz. Polyethylene	Freezing	Sample refluxed with H_2SO_4 and standard dichromate. Excess dichromate titrated with standard ferrous ammonium sulfate.	COD, mg/kg	Champaign IEPA Lab
Total Mercury (Hg)	8 oz. Polyethylene	Freezing	Digestion with H_2SO_4 and potassium persulfate to convert all forms to inorganic Hg, followed by stannous chloride reduction step to convert all inorganic Hg to metallic Hg, then measurement by cold vapor atomic absorption.	mg/kg Hg	Champaign IEPA Lab
Total Metals:* Cadmium (Cd) Chromium (Cr) Copper (Cu) Iron (Fe) Lead (Pb) Manganese (mn) Zinc (Zn)	8 oz. Polyethylene	Freezing	Digestion of prepared powder with conc. HNO_3 for 30 minutes at 100°C followed by similar digestion after addition of 6M HCl. Analysis by direct aspiration atomic absorption.	mg/kg Cd mg/kg Cr mg/kg Cu mg/kg Fe mg/kg Pb mg/kg Mn mg/kg Zn	Champaign IEPA Lab
Total Arsenic* (As)	8 oz. Polyethylene	Freezing	After digestion with persulfate, all forms of arsenic are reduced with sodium borohydride to arsine which is then burned in quartz furnace to produce atomic arsenic vapor which is measured by atomic absorption.	mg/kg As	Champaign IEPA Lab
Organics: Aldrin Chlordane DDT, SUMDDT Dieldrin Endrin Heptachlor Heptachlor epoxide. Lindane Methoxychlor PCBS, PCB1254	1 pt. glass	Freezing	Known amount of sediment is slurried with water and extracted with 50:50 methylene chloride-hexane mixture. Extract is dried with anhydrous N_2SO_4 and concentrated by evaporation. The extract is then run through a florisil cleanup and separation procedure. Fractions are concentrated and analyzed by electron-capture gas chromatography.	ug/kg	Springfield IEPA Lab
Percent Volatile Residue	8 oz. Polyethylene	Freezing	Weight loss of dried sample after ignition in muffle furnace at 600°C.	% dry wt.	Champaign IEPA Lab

*With the exception of mercury, all inorganic analysis were performed on samples dried at 103°C. All results reported on dry weight basis.

downstream of several discharges, they were generally categorized based on nearest discharger. The term "background" was used to denote sites judged unimpacted by point or non-point discharge with the exception of agricultural non-point inputs.

Results and Discussion

Stream sediment data were analyzed to establish background levels and sediment chemistry characteristics at: 1) varying distances downstream from municipal wastewater treatment facilities, and 2) sampling locations impacted by various point and non-point discharge types (i.e., pollutional sources) (Table 2).

In many cases, the most elevated sediment concentrations for a particular constituent were found in the Des Plaines River Basin. A multitude of discharges are associated with the Chicago Metropolitan area; therefore, it is not surprising that the Skokie, Cal-Sag, Grand Calumet, Des Plaines, and sections of the Illinois River contained exceptionally high concentrations of several constituents based on comparison with background means.

Although sediment sampling was biased toward urban areas and point discharges, a sufficiently large sample of background sites was available for most constituents so that "background levels" could be established (Table 3). The designation of background was somewhat qualified, however, since sites subject to non-point agricultural runoff, but not other discharges, were included in the definition. Background sites were typically on low order streams. Background concentrations will allow interpretation of sediment analyses based upon an established norm.

Of the 556 sites sampled from 1974 through 1980, adequate descriptive information existed to classify 533 into the eight designated Sample Location Categories (see Table 2). Seventy five percent of all samples collected fell into three categories: municipal wastewater treatment plants, urban and background. The majority of sediment sampling sites (208 sites or 39 percent) were placed into the municipal wastewater treatment category (Figure 1). Sites classified as influenced by urban runoff consisted of 18.6 percent, followed by background sites, with 18 percent.

Because of the relatively large sample size for the municipal category, it was possible to subdivide these sites into groups with respect to distance below the municipal source (i.e., Stream Distance Group; see Table 2). When significant differences in constituent means were detected between background and the MWWTP categories, an analysis of sediment data for that parameter was performed by Stream Distance Group (see Table 4).

Table 4 summarizes the data by distance group for each parameter considered. In almost every case the greatest percent decrease in means occurs between distance groups three and four. For two of the parameters, total

TABLE 2. Summary of Illinois river basins, sample location categories and stream distance groups used in analysis of 1974-1980 stream sediment data.

ILLINOIS FIVER BASINS

B	Big Muddy
C	Central Mississippi
D	Des Plaines
E	Fox
F	Illinois
G	Kankakee
H	Kaskaskia
I	North Central Mississippi
J	North Mississippi
K	Ohio
L	Rock
M	Sangamon
N	South Central Mississippi
O	South Mississippi
P	Wabash

SAMPLE LOCATION CATEGORIES

1	Background
2	Municipal (MWWTP)
3	Lagoon
4	Mine
5	Urban
6	Miscellaneous
7	Industrial (IWWTP)
8	Illinois Border Site

STREAM DISTANCE GROUPS

1	<1		mile
2	≥1	<3	miles
3	≥3	≤5	miles
4	>5	≤10	miles
5	>10	<20	miles
6	≥20		miles

TABLE 3. BACKGROUND ILLINOIS STREAM SEDIMENT CONSTITUENT CONCENTRATIONS for samples collected 1974-1980. Grand mean constituent concentrations for all sediment samples collected 1974-1980 are presented for compari~~son.~~ All concentrations in mg/kg unless otherwise noted.

Constituent	BACKGROUND $\overline{X}$ (n)	SD	MIN	MAX.	GRAND $\overline{X}$ (n)
COD	49091 (77)	41426	14000	330000	71539 (572)
Total Kjeldahl Nitrogen	1380 (77)	924	184	4900	1913 (563)
Total Volatile Solids (%)	4.44 (73)	2.19	1.3	12	5.11 (152)
Total Phosphorus	506 (99)	304	150	1500	1085 (609)
Arsenic	5.16 (29)	2.84	2	14	5.87 (163)
Cadmium	<0.53 (123)		<0.5	2.6	2.95 (827)
Chromium	9.78 (99)	6.73	1	56	35.0 (619)
Copper	14.9 (99)	22.8	3	220	47.9 (617)
Iron	13345 (99)	4694	1240	30000	16801 (620)
Lead	16.7 (99)	10.8	4.0	73.4	128 (623)
Manganese	736 (56)	526	160	3000	677 (221)
Mercury	0.042 (99)	0.031	0.007	0.200	0.271 (625)
Zinc	50.3 (99)	29.5	15	185	203 (623)
Chlordane (ug/kg)	<5.00 (7)		<5.00	7.2	<9.54 (97)
Sum DDT (ug/kg)	<5.00 (26)		<5.00	24	<39.9 (233)
DDT (ug/kg)	<2.21 (43)		<2.00	14	<17.6 (301)
Dieldrin (ug/kg)	<4.30 (123)		<1.00	68	<5.03 (627)
Heptachlor epoxide (ug/kg)	<1.25 (68)		<1.00	6	<2.48 (517)
PCB 1254 (ug/kg)	<2.96 (25)		<2.00	15	<21.5 (194)
PCBS (ug/kg)	<10 (46)		<10	60	<354 (353)

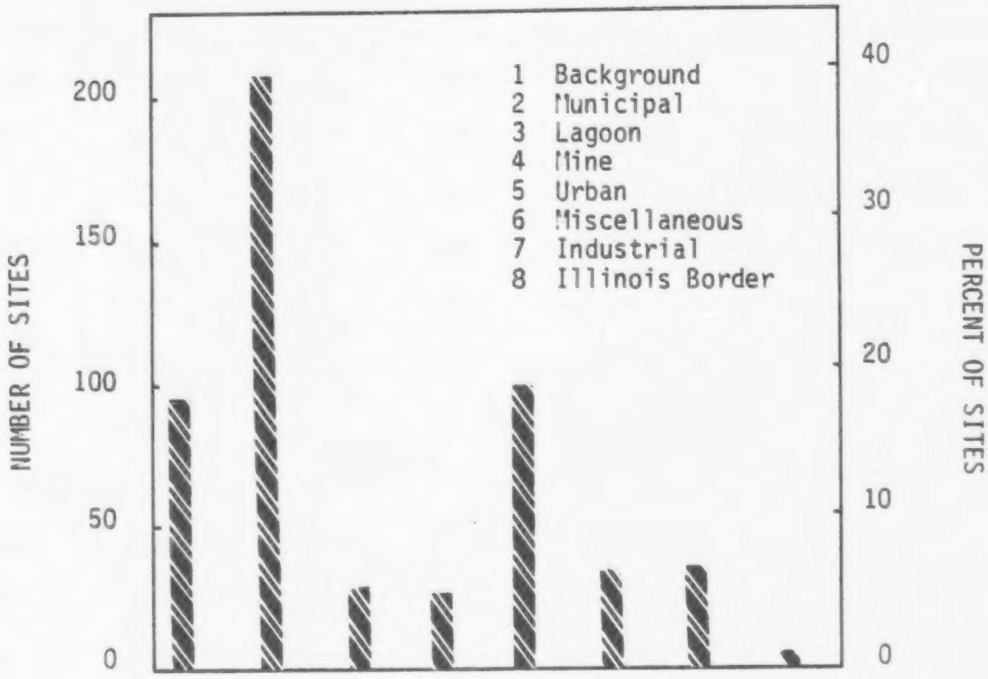

FIGURE 1. Distribution of sediment sampling sites with respect to Sample Location Category.

phosphorus and mercury, means are particularly high for Distance Group 3. These elevated means are the result of single high sample values. Intuitively one would think that the closer samples are collected to a discharger, the more frequently elevated concentrations should be encountered; these data, however, suggest relatively little difference within the first five stream miles.

Sediment samples were collected in every major river basin in conjunction with CORE station, basin, and intensive survey sampling conducted from 1974 through 1980. Sampling was not random, however, nor was it proportional to basin size. Approximately one half of all samples were collected in the Kaskaskia, Des Plaines and Illinois River Basins. Four other basins, the Rock, Sangamon, Wabash and Big Muddy, received considerable sampling effort. Statewide, the distribution of sediment sampling sites was largely restricted to areas where major water quality studies were conducted. The locations of these studies were predominantly related to the size and number of point source discharges and/or urban areas within a basin, although a special effort was made in 1975 to restrict sampling to background locations.

Of 15 river basins in which sediment was collected, only the Des Plaines Basin consistently exhibited elevated constituent concentrations. This basin ranked first in mean concentrations for 14 parameters, second for three, and third for two (Table 5). The mean concentration of mercury in the Des Plaines Basin was six times higher than the next highest basin mean; PCB concentrations were also highly elevated in the Des Plaines. Manganese, which exhibited a near-normal distribution and did not appear elevated downstream from point source discharges, was the only parameter not found at elevated concentrations in the Des Plaines Basin.

INDIVIDUAL PARAMETER EVALUATION

Total volatile residue, chemical oxygen demand (COD) and total Kjeldahl nitrogen were highly intercorrelated. In general, highest concentrations were downstream of wastewater treatment plants (MWWTPs) and urban areas. Analysis of COD data indicated a return to near background levels at distances greater than five miles downstream of MWWTPs. Highest concentrations were encountered in a small section of the Grand Calumet River.

Highest arsenic concentrations were associated with mine or urban discharges (and concentrated in the northeastern corner of the state). However, the single highest concentration was found below a MWWTP (49 mg/kg As). Most sites, irrespective of geographic location or discharge type, evidenced concentrations which could be considered background.

Sediment cadmium concentrations were generally quite low, often below the minimum detectable level. The single highest concentration (154 mg/kg) was found below an enamel plating factory in the Kaskaskia Basin; however, the majority of elevated levels were in the Des Plaines Basin. Elevated concentrations were also found below fluorspar mines in Hardin County.

TABLE ~~4~~. Mean constituent concentrations by stream distance below municipal waste water treatment plants (MWWTP). All concentrations in mg/kg except pesticides and PCB's which are in ug/kg sediment dry weight. Number in parenthesis is sample size.

DISTANCE GROUP	1	2	3	4	5	6
Distance Below MWWTP (in miles)	<1	≥1 <3	≥3 ≤5	>5 ≤10	>10<20	≥20
COD	87000 (40)	120000 (53)	93000 (41)	54000 (36)	38000 (25)	30000 (15)
Total Kjeldahl-N	3439 (38)	2336 (53)	2430 (42)	1450 (36)	1336 (25)	1229 (15)
Total Phosphorus	1764 (39)	1437 (53)	3649 (43)	879 (39)	509 (33)	533 (16)
Arsenic	4.6 (9)	5.9 (11)	11.3 (10)	4.3 (14)	3.9 (11)	4.9 (4)
Cadmium	<5.0 (53)	<2.7 (74)	<4.7 (59)	<2.9 (51)	<0.9 (38)	<0.6 (19)
Chromium	43.8 (39)	46.3 (53)	62.7 (43)	31.6 (39)	17.0 (33)	15.6 (16)
Copper	89 (39)	61 (53)	59 (43)	44 (37)	29 (32)	29 (16)
Iron	18000 (39)	19000 (53)	25000 (43)	14000 (39)	13000 (33)	15000 (16)
Lead	142 (39)	258 (53)	114 (43)	49 (39)	23 (33)	16 (16)
Manganese	921 (7)	673 (11)	680 (12)	588 (15)	655 (14)	880 (5)
Mercury	0.32 (38)	0.31 (53)	0.97 (43)	0.17 (39)	0.08 (33)	0.04 (16)
Zinc	292 (39)	317 (53)	375 (43)	144 (39)	69 (33)	66 (16)
Chlordane	<5.0 (3)	<7.2 (6)	<7.1 (8)	<8.9 (10)	<6.0 (5)	<5.0 (1)
DDT	<26.3 (20)	<26.7 (27)	<14.8 (27)	<4.1 (16)	<4.3 (10)	<3.1 (5)
Dieldrin	<9.6 (53)	<6.8 (74)	<5.0 (59)	<3.8 (51)	<2.7 (38)	<2.0 (19)
Heptachlor epoxide	<5.8 (37)	<3.6 (46)	<3.0 (42)	<1.6 (35)	<1.0 (21)	<0.9 (7)
PCBs	<578 (23)	<773 (33)	<357 (30)	<212 (22)	<30 (14)	<10 (2)

TABLE 5. Ranking of river basin means by constituent. One (1) denotes highest basin mean, two (2) second highest and three (3) third highest.

	BASIN														
Constituent	Big Muddy	Central Miss.	Des Plaines	Fox	Illinois	Kankakee	Kaskaskia	N. Central Miss.	North Miss.	Ohio	Rock	Sangamon	S. Central Miss.	South Miss.	Wabash
COD			1	2		3									
Total Kjeldahl Nitrogen			1	2			3								
Total Volatile Solids	3		2	3											
Total Phosphorus	3	2	1												
Arsenic			2			1				3					
Cadmium			2					3		1					
Chromium			1					2							3
Copper			1							2					3
Iron	2		1							3					
Lead			1							2	3				
Manganese		1									2				3
Mercury			1					2			3				
Zinc			1							2			3		
Chlordane	2		1												3
Sum DDT			1		2	3									
DDT			1			3						2			
Dieldrin			3				1								2
Heptachlor Epoxide			3				1					2			
PCB 1254	3		2		1										
PCBS	2		1				3								

Highest sediment chromium concentrations were found in the Des Plaines Basin and were associated with MWWTP, industrial or urban discharges. An evaluation of sediments collected downstream of MWWTPs indicated a significant reduction in mean concentration at distances greater than ten miles.

The Des Plaines and Ohio Basins evidenced statistically greater mean sediment copper concentrations than remaining basins. Elevated copper levels in the Des Plaines Basin were associated with a myriad of possible discharge types while elevated levels in the Ohio were attributable to coal mining impacts.

Mean iron concentrations in sediment taken downstream of mine, urban, and MWWTP discharges were statistically higher than background means; however, these higher means were less than twice as great as the background. The majority of extreme values were confined to the Des Plaines. Although the single highest concentration (150 g/kg) was found in the Big Muddy Basin downstream from Murphysboro. By sample location category, iron concentrations were statistically significantly higher in mined areas.

The mean lead concentration for samples taken in the Des Plaines Basin (Table 6) was more than twenty times greater than the background. While elevated levels could in many cases be associated with point sources discharges, much of the lead in Des Plaines Basin sediments might have been attributable to transport in urban runoff or lead deposited as a result of fuel combustion. Outside of the Des Plaines Basin, elevated levels were also found associated with a fluorspar mine in the Ohio River Basin.

Of all the parameters monitored, only manganese appeared normally distributed (Figure 2). Although not significantly different it is interesting to note that the background mean exceeded all other sample location category means.

The mean mercury concentration in sediments collected downstream of urban areas was five times greater than the background mean. A similarly high mean was characteristic of MWWTPs as a group. When means were determined by basin, the Des Plaines Basin mean was significantly greater than any other basin mean, being six times greater than the highest highest mean. Examination of data collected downstream of MWWTPs by distance indicated sediment mercury concentrations did not consistently fall in the background range until 20 miles downstream.

Elevated zinc concentrations were generally associated with industrial mine, urban or MWWTP discharges and were typically found in the Des Plaines and Ohio Basins. The positive relationship evident between lead and zinc in stream sediments had been previously noted in lake sediments [1].

With some exceptions organic contaminants (pesticides and PCBs) in sediments were generally below minimum detectable levels. Ninety-seven sediment samples were analyzed for chlordane; only 35 contained greater than 5 ug/kg (the minimum detectable concentration). Only sediments collected from three basins, Des Plaines, Big Muddy, and Wabash, contained concentrations greater or equal to 10 ug/kg.

TABLE 6. Mean lead concentration (mg/kg) by basin in Illinois stream sediment samples collected 1974-1980. Duncan's multiple range ~~test~~ was used to compare basin means, and groupings were determined. Means with same letter are not significantly different.

BASIN	n	MEAN	SD	MIN	MAX	GROUPING
Des Plaines	125	477.1*	1769.5	10	18900	A
Ohio	30	74.3	162.7	4	860	B
Rock	55	59.7	114.2	6	765	B
Fox	9	59.7	48.4	3	150	B
Miss. North	7	44.6	83.0	5	232	B
Big Muddy	50	41.5	60.0	8	320	B
Illinois	84	40.7	55.7	0	329	B
Kaskaskia	110	39.7	67.7	1	392	B
Miss. South Central	8	30.4	21.8	12	76	B
Kankakee	10	28.7	18.4	6	70	B
Wabash	50	28.6	21.7	6	100	B
Sangamon	63	22.2	16.2	4	102	B
Miss. Central	3	21.0	3.6	18	25	B
Miss. North Central	2	20.0	1.4	19	21	B
Miss. South	17	19.5	12.3	9	65	B.

* deleting the extremely high 18900 value reduces the basin mean to 329 mg/kg

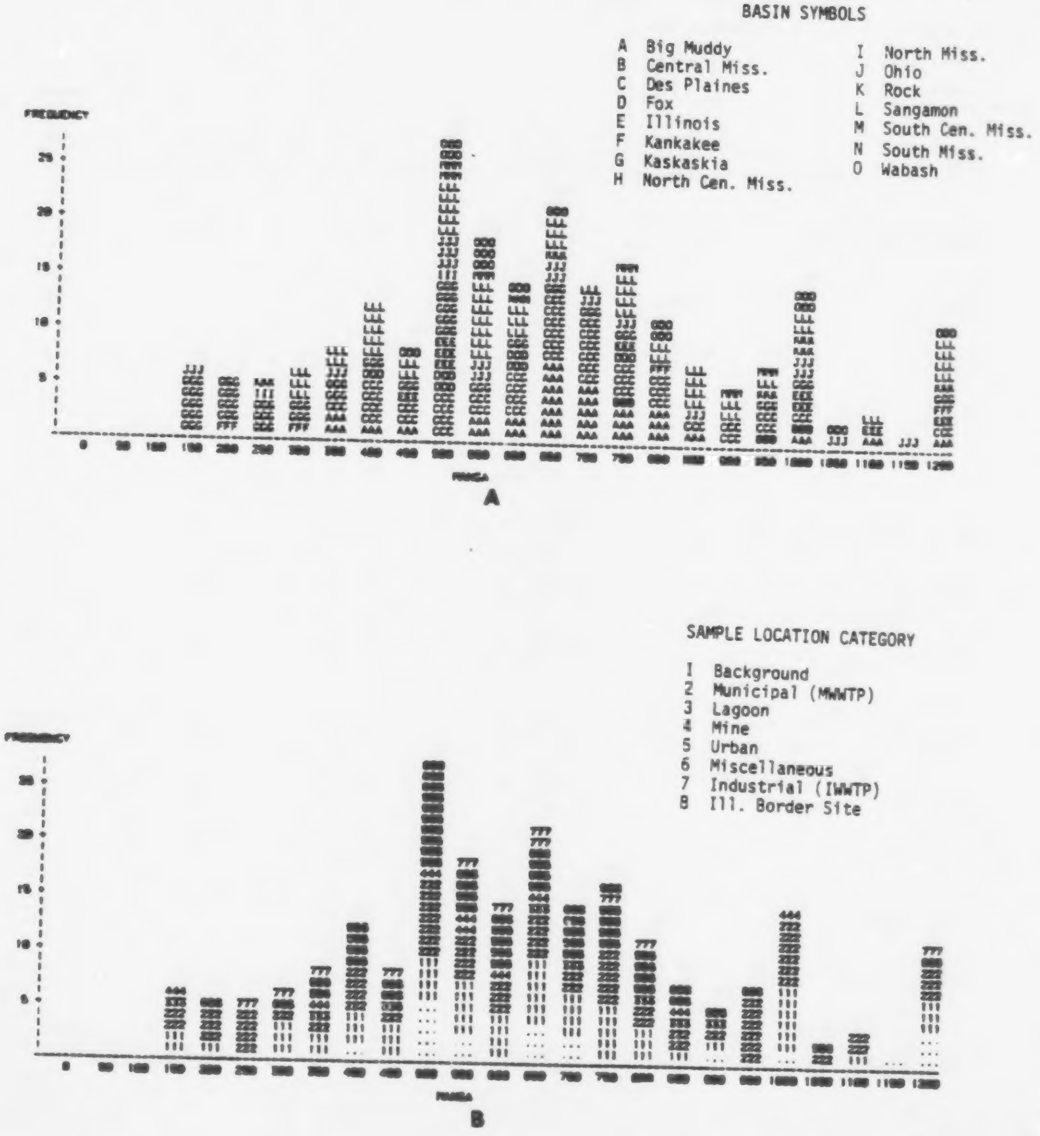

FIGURE 2. Distribution of manganese (mg/kg) in Illinois stream sediment samples by (a) Basin and (b) Sample Location Category.

Two organochlorine compounds, dieldrin and heptachlor epoxide, displayed a steady decrease in mean concentrations with increasing downstream distances. Interpretation of these data is somewhat hampered due to the number of samples with concentrations below the minimum detectable level.

Between 1974 and 1977, sediments were analyzed for the DDT analogue only. Aside from a single sediment sample taken near Taylorville, all DDT concentrations greater than 50 ug/kg were found in sediments taken in the Chicago area (i.e., Des Plaines, Calumet and Skokie Rivers). Detectable levels of DDT (maximum of 14 ug/kg) were found at background sites. The distribution of total DDT (DDT + Analogues) with respect to basin and discharge type was essentially the same as that noted for DDT. With few exceptions, total DDT greater than 50 ug/kg was associated with sediment from Chicago area river systems.

Of the 534 sediment samples analyzed for dieldrin, half contained concentrations less than the minimum detectable level (1 ug/kg). No sediment samples collected in 1979 or 1980 contained greater than 15 ug/kg.

In 1974 and 1975, sediments were analyzed for PCB-1254. Beginning in 1976 samples were analyzed for PCBs (total of all isomers). Two thirds of the sediment samples analyzed contained detectable levels of PCB-1254 (i.e., greater than 2 ug/kg). With few exceptions, concentrations greater than 100 ug/kg were associated with river sediments in the Chicago area, especially the Des Plaines and Skokie Rivers. The single highest concentration, however, was in the Illinois River south of Seneca, Illinois (1000 ug/kg). Forty-two percent of 353 samples analyzed for PCBs contained less than the maximum detectable concentration of 10 ug/kg. Twenty-two of the twenty-four sediment samples with concentrations greater than 1000 ug/kg occurred in the Des Plaines Basin. Elevated levels were generally associated with MWWTP and urban discharges although no statistical comparison was attempted due to the large number of samples that contained less than the minimum detectable concentration.

CLASSIFICATION OF ILLINOIS STREAM SEDIMENTS

For purposes of evaluating results of sediment analyses, it was desirable to develop a table of ranges against which one might judge degree of contamination. Groupings for nutrients, heavy metals and arsenic were based on standard deviations from the background mean. The classification ranges were defined as follows:

1) NON-ELEVATED - less than the sum of the background mean and one standard deviation (i.e., $<\overline{X}+1SD$)).

2) SLIGHTLY ELEVATED - equal to or greater than the background mean plus one standard deviation to less than the background mean plus two standard deviations (i.e., $\geqslant(\overline{X}+1SD)<(\overline{X}+2SD)$).

3) ELEVATED - equal to or greater than the background mean plus two standard deviations but less than the background mean plus four standard deviations (i.e., $\geqslant(\overline{X}+2SD)<(\overline{X}+4SD)$).

4) HIGHLY ELEVATED - equal to or greater than the background mean plus four standard deviations (i.e., $>(\overline{X}+4SD)$ but $<(\overline{X}+8SD)$).

5) EXTREME - equal to or greater than the background mean plus eight standard deviations (i.e., $\geqslant(\overline{X}+8SD)$).

Because cadmium and organochlorine compounds were often found at concentrations below detectable levels, it was not possible to compute true means and standard deviations. Therefore, different criteria were used to classify sediments with respect to these constituents. Ranges were established using percent exceedence and were defined as follows:

1) NON-ELEVATED - that range of concentration not exceeded by 50% of the samples analyzed.

2) SLIGHTLY ELEVATED - that range in concentration exceeded by 35 to 50% of the samples analyzed.

3) ELEVATED - that range of concentration exceeded by only 15 to 35% of the samples analyzed.

4) HIGHLY ELEVATED - that range of concentration exceeded by only 5 to 15% of the samples analyzed.

5) EXTREME - that range of concentration exceeded by no more than 5% of the samples analyzed.

COMPARISONS WITH OTHER STUDIES

Finally, Table 8 presents a comparison of Illinois stream sediment data with results from other studies. Most of the studies presented concerned a single river system, and in general, sample sizes were small relative to the

TABLE 7. Classification of Illinois stream sediments.

NUTRIENTS AND HEAVY METALS: Ranges of concentrations displayed and resultant groupings are based on one, two, four and eight standard deviations from background mean. Unless otherwise noted concentrations are in mg/kg sediment dry weight.

PARAMETER	NON-ELEVATED	SLIGHTLY ELEVATED	ELEVATED	HIGHLY ELEVATED	EXTREME
COD	<90000	≥90000	≥132000	≥215000	≥380000
Total Kjeldahl Nitrogen	<2300	≥2300	≥3200	≥5100	≥8800
Total Volatile Solids (%)	<6.5	≥6.5	≥8.8	≥13	≥22
Total Phosphorus	<80	≥80	≥1100	≥1700	≥3000
Arsenic	<8.0	≥8.0	≥11	≥17	≥28
Chromium	<16	≥16	≥23	≥38	≥60
Copper	<38	≥38	≥60	≥100	≥200
Iron	<18000	≥18000	≥23000	≥32000	≥50000
Lead	<28	≥28	≥38	≥60	≥100
Manganese	<1300	≥1300	≥1800	≥2800	≥5000
Mercury	<0.07	≥0.07	≥0.10	≥0.17	≥0.30
Zinc	<80	≥80	≥100	≥170	≥300

CADMIUM AND ORGANOCHLORINE COMPOUNDS: Ranges of concentrations and resultant groupings are based on 50, 65, 80 and 95 percent distributions for all samples. Cadmium concentrations are in mg/kg and organochlorine concentrations are in µg/kg sediment dry weight.

Cadmium	<0.5	≥0.5	≥1.0	≥2.0	≥20.0
Chlordane	<5	≥5	≥6	≥10	≥40
Sum DDT	<6.0	≥6.0	≥10	≥35	≥200
Dieldrin	<3.5	≥3.5	≥6	≥10	≥25
Heptachlor Epoxide	<1.0	≥1.0	≥1.5	≥3	≥9
PCBs	<10	≥20	≥50	≥200	≥1500

TABLE 8. Comparison of heavy metal concentrations in river sediments. All concentrations expressed as mg/kg sediment dry weight. Table after Vivian and Massie (1977) with additions. Means and ranges in concentration are given when available.

SEDIMENT SOURCE [Reference]	n	ARSENIC	CADMIUM	CHROMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC	MAJOR POLLUTIONAL SOURCE	SEDIMENT FRACTION (in um)
Cardigan Bay, Wales [7]	10		1.7 0.6-3.5		22 15-40		123 26-699			159 96-441		Total
Cardigan Bay, Wales [8]	38				43 2-610		31 11-58					Total
Rhine, West Germany [9]			9 2-23		192 42-408		251 83-566			930 250-2061		<2
Elbe, West Germany [9]			21 15-25		161 80-220		430 150-712			1425 800-2125		<2
Miateczko Slaskie, Poland [10]	21		1-116		9-226		24-490			100-5000	Zinc Plant	Total
Qishon River, Israel [11]			<-123		3-48		9-275			20-1500		<170
Ottawa River, Canada [12]	1				236		390			846	Sewage Outfall	Total
River Tawe, Wales [13]			2-335		34-2000		63-6993			306-35796	Smelting	<200
Cal-Sag Channel, Illinois [14]		19 9.4-42	9.4 3.7-18	110 26-360	120 68-180		500 210-990		<0.42 <0.02-2.3	2580 500-9400		Total
Rio Puerco, New Mexico [15]		1.3-333	0.06-1.7		0.72-6.5		0.5-10		0.42-2.0	27-65	Uranium Mining	Total
Fowey, Red, Carnon and Gannel Rivers, England [16]	120		1-35		8-6500	6500 99000	10-4410	90-6100		31-7000	Uncontaminated and mining activity	
Willamette River Basin [17]	40 43	13 10-20	1.0 0.5-2.5	57 40-100	42 30-95		38 10-120		0.16 0.02-0.38	249 115-1215	Relatively Unpolluted	<20
Michigan Background Stream Sites [6]	28	0.4 0-2	4.2 0-11	1.6 0-5			36.9 1-96		0.19 0.12-15.0	31.3 4-210	Unpolluted	<20
Michigan Industrial Municipal Sites [6]	46	12.5 1.1-92	6.48 0.18-37.4	211 3-20390	545 19-3657				1.89 0.01-38.2	90.6 0.8-729	Industrial Municipal	Total
Illinois - Statewide [present study]	variable	5.87 1-49	2.95 0.5-154	35 0.12-770	47.9 0.850	16801 280-150400	127.8 400-18900	677 150-3000	0.27 0.002-30	20.3 4.8-5600	Background to Extremely Polluted	Total
		n=563	n=827	n=619	n=617	n=620	n=623	n=221	n=625	n=623		

data presented here. Considering the range in type of sites sampled with respect to dischargers, it is not surprising that sediment concentration ranges for Illinois stream data generally encompass all other study ranges. The reader will note the variability in sediment particle size fractions analyzed which undoubtedly affects the validity of between-study comparisons due to differential sorption according to particle size [4,5]. A comparison of our background data (Table 3) with similar data for Michigan is informative [6]. In general, background levels established for Illinois are slightly greater than Michigan's, and may be attributable to agriculturally impacted sites allowed by definition into the Illinois background site category.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of many individuals, some unknown to the authors, who collected and analyzed stream sediment samples over the period, 1974-1980. Samples were collected by Monitoring Unit Staff: R. Schacht, W. Matsunaga, and H. Essig in IEPA's Maywood office, W. Tucker and B. Ettinger in the Springfield office, and R. Hite and M. King of the Marion office. Numerous other individuals including J. Levesque, student workers and Springfield staff assisted at various times in sample collection and data processing. Laboratory analysis was performed in IEPA laboratories in Champaign and Springfield, under the direction of R. Frazier and J. Hurley, respectively. Table preparation and typing of rough and final drafts were accomplished by M. Kinsall and B. Richards.

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ACCUMULATION OF SEDIMENT AND HEAVY METALS IN LAKE ELLYN, AN URBAN LAKE AT GLEN ELLYN, ILLINOIS

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INTRODUCTION

Detention storage of urban-stormwater runoff is an accepted management strategy to reduce loads of contaminants in streams [1]. It is effective in reducing the load of sediment and sediment-associated chemical constituents delivered to receiving waters, thus producing a regional benefit. However, sediment accumulation in lakes reduces stormwater-storage capacity and contaminants may accumulate in the lake bottom sediments.

Accumulations of sediment and associated heavy metals were studied at Lake Ellyn, a 10.2-acre urban lake, located in Glen Ellyn, Illinois, a western suburb of Chicago (figure 1). This paper describes the distribution and character of bottom sediments deposited in Lake Ellyn between 1970 and 1980.

ACKNOWLEDGMENTS

This study was supported by Northeastern Illinois Planning Commission as part of the Nationwide Urban Runoff Program. A more detailed version of this paper was submitted to the Department of Geology, Northern Illinois University, as partial fulfillment of the author's Master of Science Degree [2].

STUDY AREA

Lake Ellyn receives surface drainage from a 534-acre, fully developed, urban watershed. Table 1 lists the distribution of land use in the watershed. Surface-water runoff enters the lake through storm drains and by overland flow. The principal inflow (Main Inlet) delivers runoff from approximately 70 percent of the watershed. Lake outflows are located on the opposite side of the lake from the Main Inlet. Uses of Lake Ellyn include runoff storage and noncontact recreation.

PHYSICAL CHARACTERISTICS OF LAKE ELLYN

Lake Ellyn contains 44.3 acre feet of water at the normal pool elevation of 707.60 feet. Surface area is 10.2 acres. The lake is divided into two basins by an underwater rock-barrier dam (figure 1).

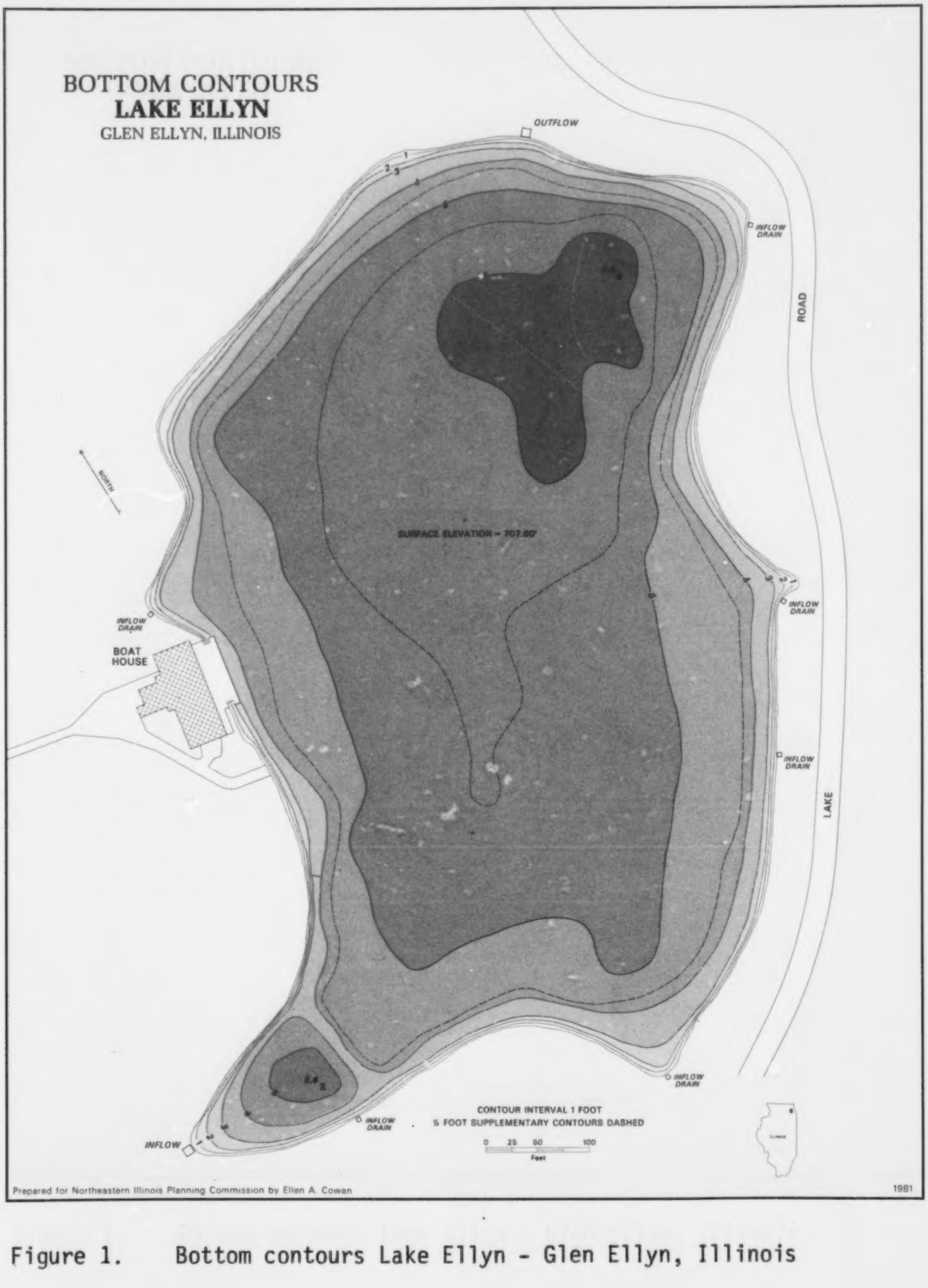
BOTTOM CONTOURS
LAKE ELLYN
GLEN ELLYN, ILLINOIS
OUTFLOW
INFLOW DRAIN
ROAD
NORTH
SURFACE ELEVATION = 707.80'
INFLOW DRAIN
BOAT HOUSE
INFLOW DRAIN
LAKE
INFLOW DRAIN
INFLOW DRAIN
INFLOW
CONTOUR INTERVAL 1 FOOT
½ FOOT SUPPLEMENTARY CONTOURS DASHED
0 25 50 100
Feet
ILLINOIS
Prepared for Northeastern Illinois Planning Commission by Ellen A. Cowan
1981

Figure 1. Bottom contours Lake Ellyn - Glen Ellyn, Illinois

Table 1. Land use in the Lake Ellyn watershed as a percentage of drainage area (from Hey and Schaefer, 1983).

Type of land use	Percent
Low density single family residential	80
High density residential	3
Commercial	5
Under construction (bare surface)	0
Wetland	2
Parkland	5
Institutional	5
Total	100

The small basin nearest the Main Inlet is designed as an in-lake sedimentation basin. Maximum depth in the lake is 6.4 feet, and mean depth is 5.0 feet.

FIELD METHODS

Data were collected at Lake Ellyn during the fall of 1980. Depth of water to sediment, and thickness of bottom sediments were measured in the lake at 380 points along a transect system (figure 2). Measured depths were used to construct bathymetric and sediment thickness maps (figures 1 and 3). Sediment maps represent deposition during a 10-year period following dredging in 1970.

Sediment cores were collected along transects using a US BMH-53 core sampler [3].

RESULTS

SEDIMENTATION RATES

Areal distribution of bottom sediments is shown in figure 3. The inlet side of the barrier dam retained the greatest thickness of sediment, where a maximum thickness of 3.3 feet was measured. Sediment thicknesses were between 1.0 and 2.0 feet adjacent to the north side of the barrier dam and at the north end of the lake. Sediments ranged from 0.5 to 1.0 foot in thickness near smaller inflow drains, and were less than 0.5 foot thick near the shoreline, on the barrier dam, and near the middle of the lake.

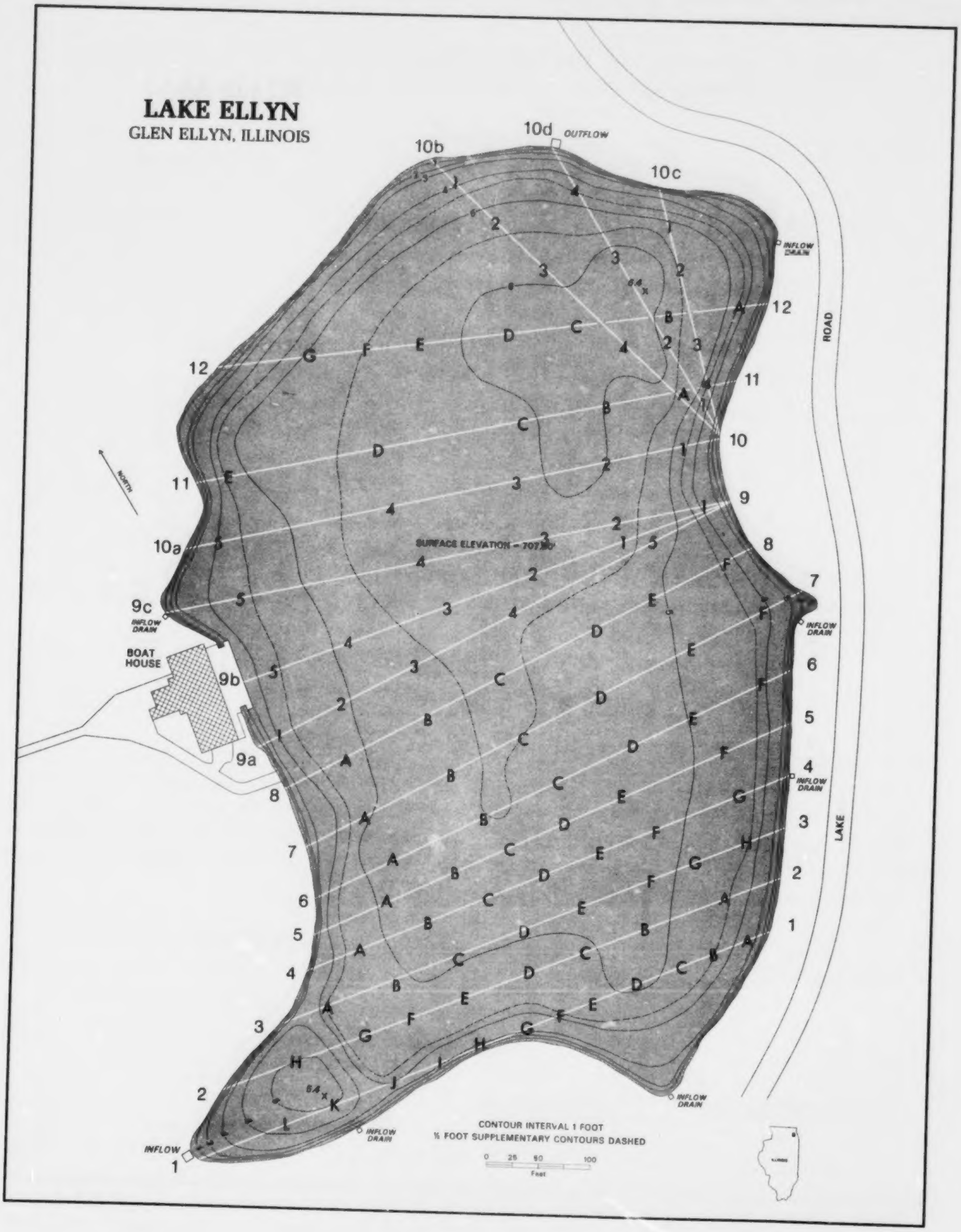
LAKE ELLYN
GLEN ELLYN, ILLINOIS
10b
10d
OUTFLOW
10c
INFLOW DRAIN
12
11
10
9
8
7
6
5
4
3
2
1
10a
9c
9b
9a
BOAT HOUSE
NORTH
ROAD
LAKE
SURFACE ELEVATION – 707
INFLOW
CONTOUR INTERVAL 1 FOOT
½ FOOT SUPPLEMENTARY CONTOURS DASHED
0 25 50 100
Feet

Figure 2. Map of transects and sample locations in Lake Ellyn. Numbers and letters at the shoreline refer to transects and those within the lake refer to sample locations.

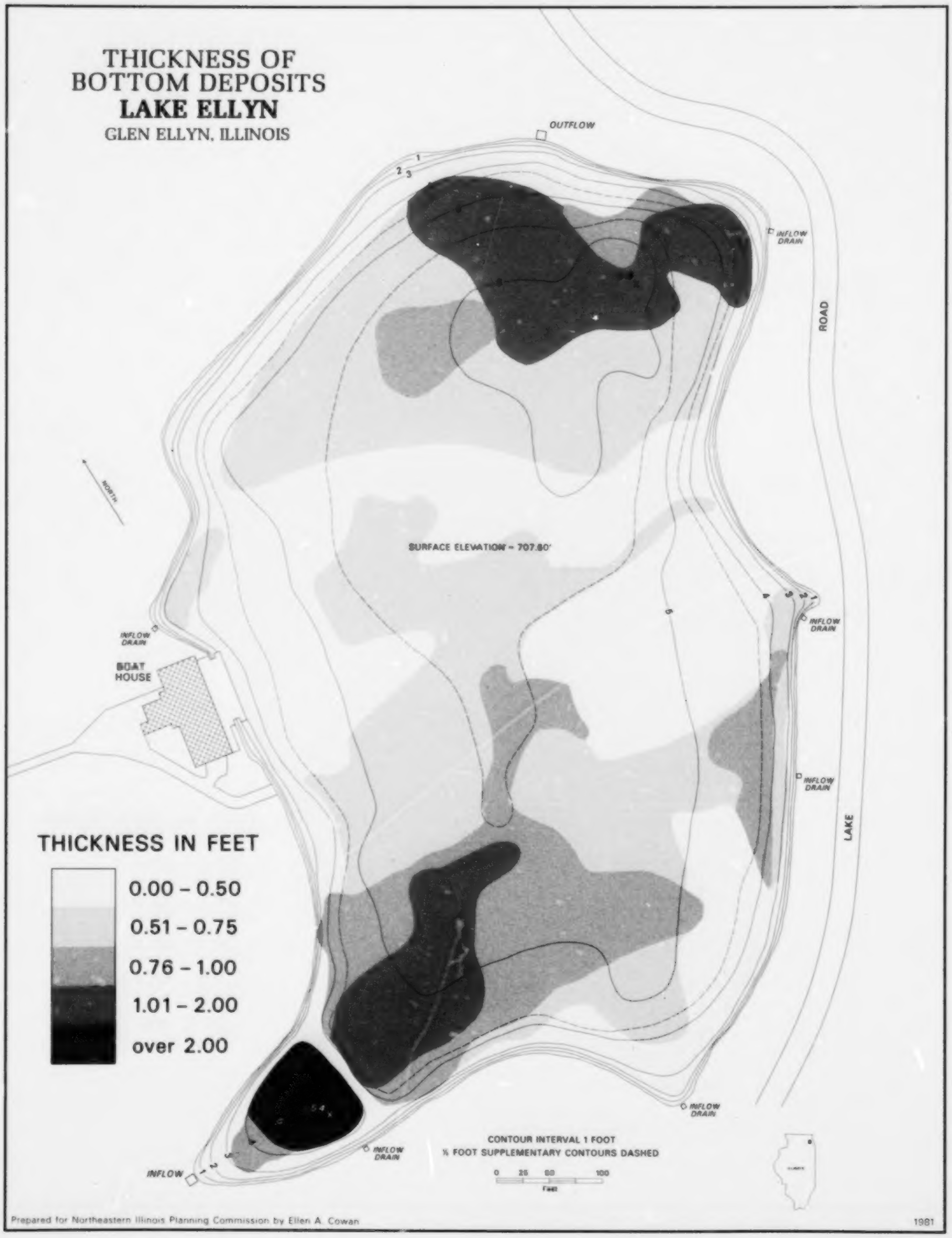
THICKNESS OF BOTTOM DEPOSITS
LAKE ELLYN
GLEN ELLYN, ILLINOIS
OUTFLOW
INFLOW DRAIN
ROAD
NORTH
SURFACE ELEVATION = 707.60'
INFLOW DRAIN
BOAT HOUSE
INFLOW DRAIN
INFLOW DRAIN
LAKE
THICKNESS IN FEET
0.00 – 0.50
0.51 – 0.75
0.76 – 1.00
1.01 – 2.00
over 2.00
INFLOW DRAIN
INFLOW DRAIN
INFLOW
CONTOUR INTERVAL 1 FOOT
½ FOOT SUPPLEMENTARY CONTOURS DASHED
0 25 50 100
Feet
Prepared for Northeastern Illinois Planning Commission by Ellen A. Cowan
1981

Figure 3. Thickness of bottom deposits Lake Ellyn - Glen Ellyn, Illinois.

A mean sedimentation accumulation rate of 0.8 inch per year was calculated from field data. This is a volume of 0.68 acre-foot of sediment accumulation per year. Sediment accumulation since 1970 accounts for 13 percent of Lake Ellyn's volume.

SEDIMENT CHARACTERISTICS

Cores of bottom sediments from Lake Ellyn were composed of homogeneous, fine-grained sediments containing a high content of organic material. Sediments were black and those near the inflows had what appeared to be an oily coating and odor. This probably results from sediment absorption of grease and oil originating from road surfaces.

Particle-size distributions were determined by sieve analysis for the fraction greater than 62 micrometers and pipet analyses for the fraction less than 62 micrometers [4]. Mean particle sizes were calculated according to methods described by Inman [5]. Areal distribution of mean particle sizes is presented in figure 4. The distribution is skewed towards the silt- and clay-size classes. The finest mean particle sizes were for samples from the deepest areas of the lake. Sediment in near-shore areas had a wider mean-particle size range because of erosion of sand and gravel from the bank. The coarsest sediment was deposited near the Main Inlet. The mean size of bottom sediments decreases with distance from the Main Inlet due to reduction in input water velocity.

SETTLING RATES

The settling velocity of silt- and clay-size particles is described theoretically by Stokes' Law. The settling rate of suspended solids entering Lake Ellyn was calculated by using the range of particle sizes of suspended sediment entering through the Main Inlet. The lower envelope in figure 5 defines the theoretical range of settling velocities estimated from measured particle sizes. After 4 hours, the maximum percentage of solids removed from the water column should be about 45 percent.

Measurements of the settling rates of stormwater samples showed that approximately 95 percent of the suspended solids would settle in 4 hours [6]. This suggests flocculation of the particles, probably due to high concentrations of clay-size sediment and colloidal organic material. Particles cohere as chains or clumps which settle more rapidly than discrete particles.

HEAVY METALS IN BOTTOM SEDIMENT

Concentrations of cadmium, copper, iron, lead, and zinc in bottom sediments were determined using atomic absorption spectrophotometry. Analyses were performed on size fractions less than, or greater than, 62 micrometers, and on whole samples. Results are listed in table 2.

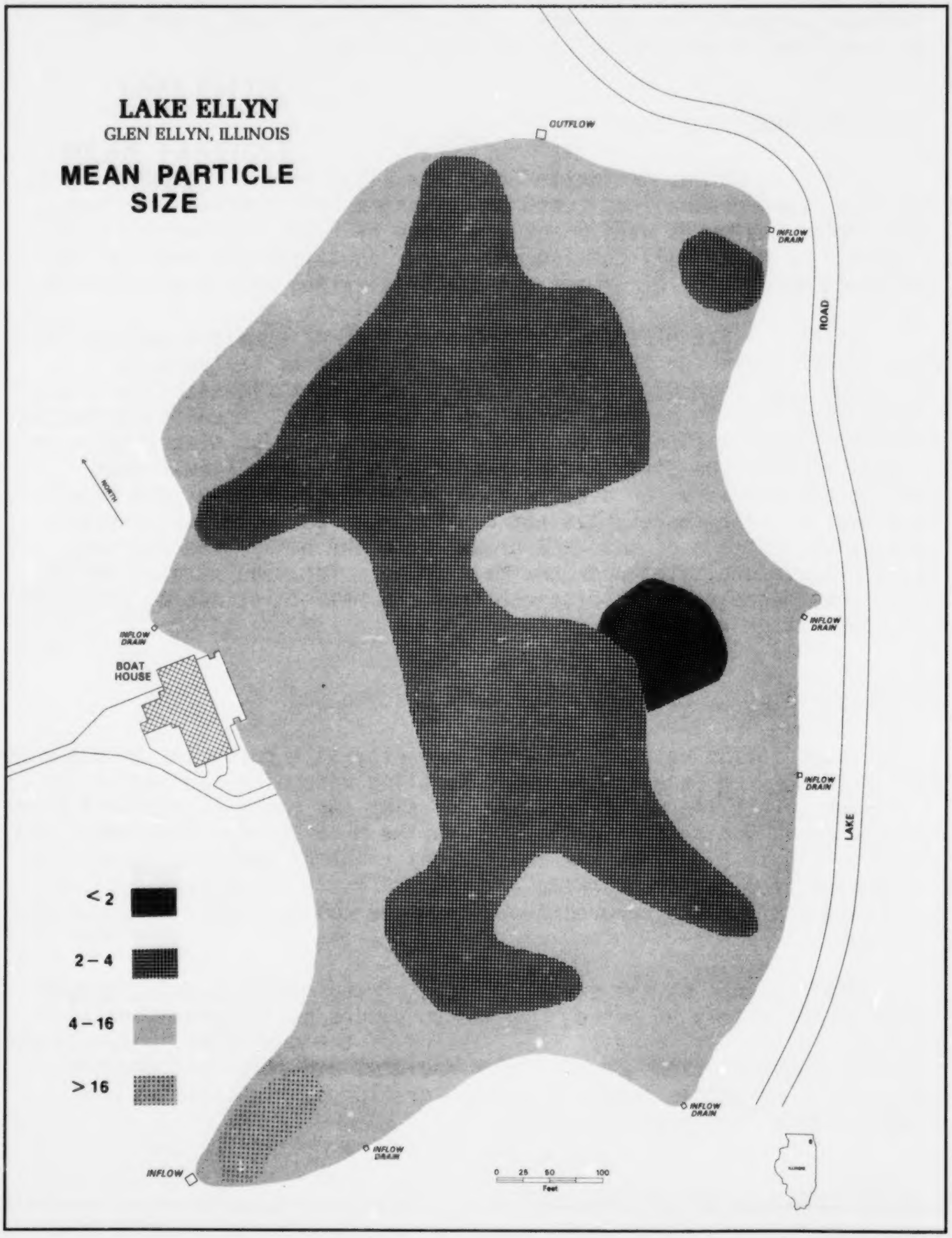
LAKE ELLYN
GLEN ELLYN, ILLINOIS
MEAN PARTICLE SIZE
OUTFLOW
INFLOW DRAIN
ROAD
NORTH
INFLOW DRAIN
BOAT HOUSE
INFLOW DRAIN
INFLOW DRAIN
LAKE
< 2
2 – 4
4 – 16
> 16
INFLOW DRAIN
INFLOW DRAIN
INFLOW
0 25 50 100
Feet

Figure 4. Mean particle size in bottom sediments in micrometers.

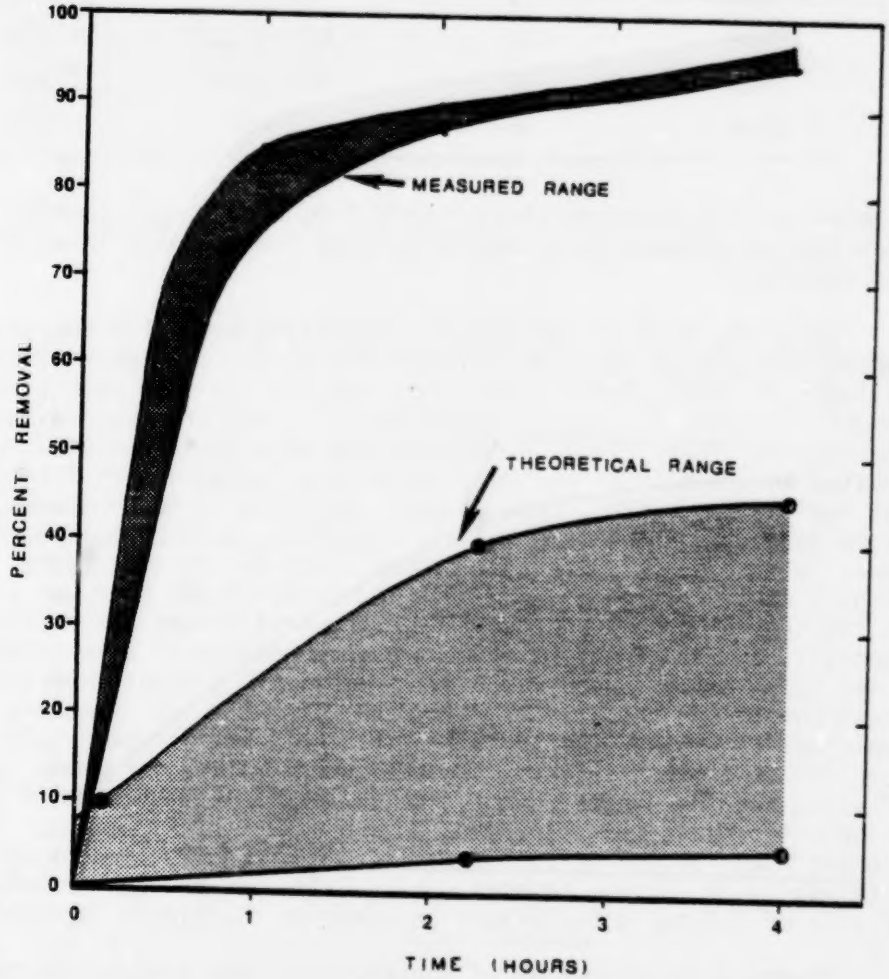

Figure 5. Ranges of settling rates of suspended solids from stormwater runoff, Lake Ellyn, Illinois.

Table 2. Constituent concentrations recovered from Lake Ellyn bottom sediment, in milligrams per kilogram dry weight.

Metallic constituent	Number of samples	Constituent concentrations, in milligrams per kilogram	
		Range	Mean
Cadmium	7	3-6	4
Copper	15	73-792	250
Iron	15	3,630-28,000	19,420
Lead	15	407-5,140	1,590
Zinc	15	3-499	210

Cadmium was not detected (less than 0.5 mg/kg) in most samples. The mean cadmium concentration was calculated from samples in which cadmium was detected.

Kelly and Hite [7] devised a classification of Illinois lake sediments based on chemical constituents in 273 samples collected from 63 lakes in 1979. Their classifications for the five metals analyzed appears in table 3. Lakes studied by Kelly and Hite were diverse in physiography, morphology, hydrology, and watershed land use. Lakes located in urban areas included the Skokie Lagoons, Cook County, and the Fox Chain of Lakes, Lake County. Relative to their scheme, Lake Ellyn bottom sediments are "highly elevated" in cadmium, copper, and lead, "elevated" in zinc, and "normal" in iron concentrations. The highest concentration of lead reported by Kelly and Hite was 250 mg/kg in the Skokie Lagoons and the mean concentration was 152 mg/kg. In contrast, the highest lead concentration measured in Lake Ellyn was 5,140 mg/kg and the mean was 1,590 mg/kg. The highest mean concentrations for copper reported by Kelly and Hite were in lakes used for municipal water supplies in central Illinois where copper sulfate was used for control of algae. The mean concentration for these lakes was 42 mg/kg and the highest concentration was 560 mg/kg compared to Lake Ellyn which had a mean of 250 mg/kg and a high of 790 mg/kg. The highest mean concentration for zinc (403 mg/kg) reported by Kelly and Hite was in the Skokie Lagoons. Lake Ellyn had a mean concentration of zinc of 210 mg/kg, only half as large as the Skokie Lagoons.

Figure 6 shows sources of copper, lead, and zinc in the Lake Ellyn watershed. These sources [6] may be outside the watershed, for example, industrial areas near Chicago, or within the Lake Ellyn watershed. Metals may be airborne to the watershed and deposited by rain, snow, and dry deposition from the atmosphere. Hey and Schaefer [6] estimate 10 percent of the copper, 5 percent of the lead, and 23 percent of the zinc are from these sources. They describe major sources of metals within the watershed as including traffic, and decomposition of pavement and construction materials. Vehicular exhaust, and the wear of tires and brake linings contribute 62 percent of the copper, 87 percent

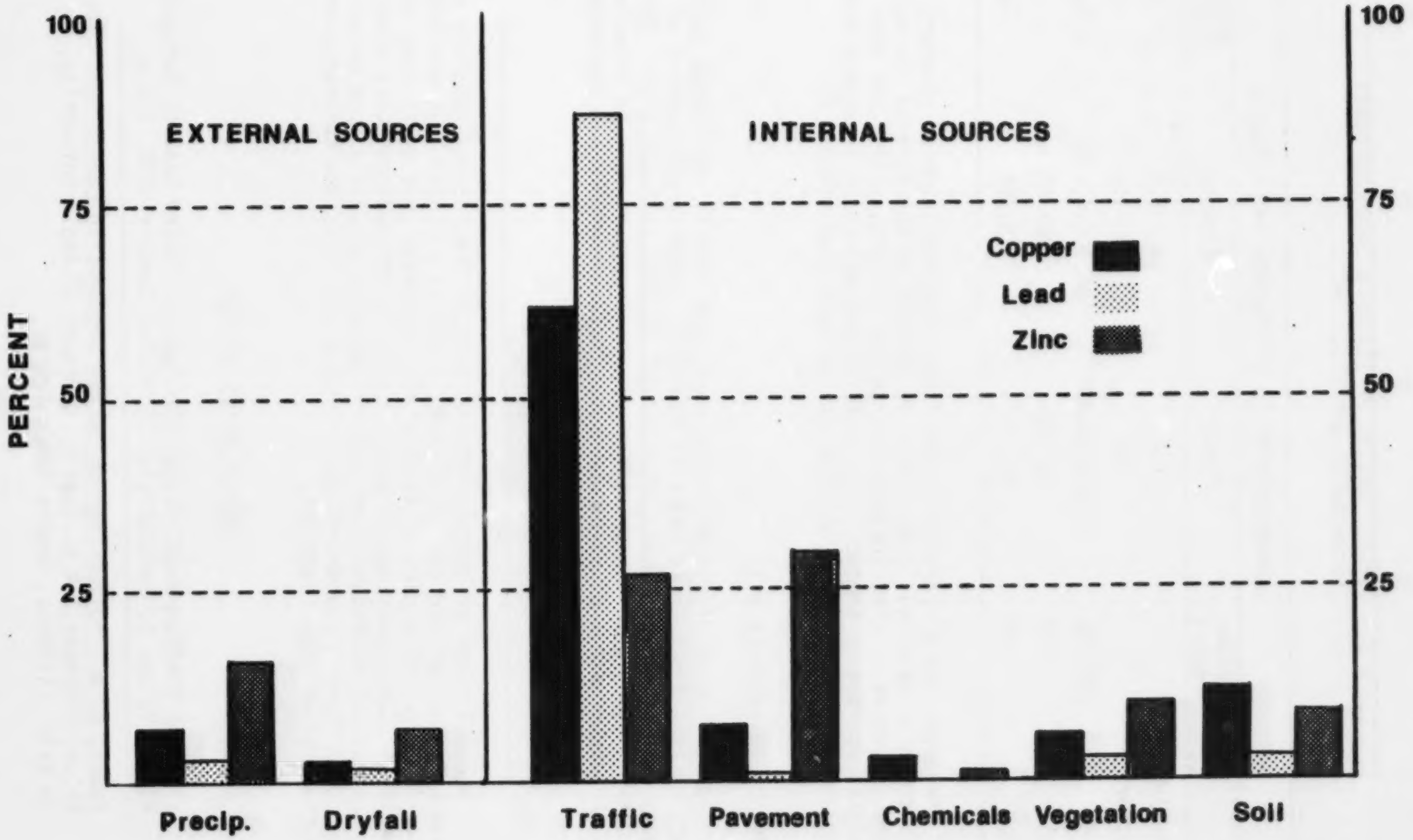

Figure 6. Sources of heavy metals in the Lake Ellyn watershed. (Data from Hey and Schaefer, 1983.)

Table 3. Classification of Illinois lake sediments (from Kelly and Hite, 1981).

Metal	Concentration in milligrams per kilogram			
	Below normal	Normal	Elevated	Highly elevated
Cadmium		1.8	1.8-2.6	>2.6
Copper		100	100-150	>150
Iron	<18,000	18,000-36,000	36,000-45,000	>45,000
Lead	<15	15-100	100-150	>150
Zinc	<50	50-175	175-250	>250

of the lead, and 27 percent of the zinc. Decomposition of pavement and construction materials contributes 30 percent of the zinc to the watershed. Sources of zinc included galvanized gutters, nails, and wear of painted surfaces. Chemical use, vegetation, and soils introduce minor amounts of copper, lead, and zinc to the watershed (figure 6).

EFFECTS OF PARTICLE SIZE

Distribution of copper, lead, iron, and zinc in the bottom sediment by size fraction is shown in figure 7. Mean concentrations of heavy metals were inversely proportional to mean sediment size. This suggests that higher concentrations of heavy metals would be expected in the deeper areas of lakes where the finest sediments are deposited.

CONCLUSIONS

Accumulations of bottom sediment reduced the storage capacity of Lake Ellyn during the period 1970-80, although a barrier dam was effective in restricting much of the incoming sediment to a small area in the lake. Concentrations of heavy metals in the sediment were elevated as a result of atmospheric and water transport of metals from urban sources. Highest concentrations of heavy metals in the sediments were in the smaller size fractions.

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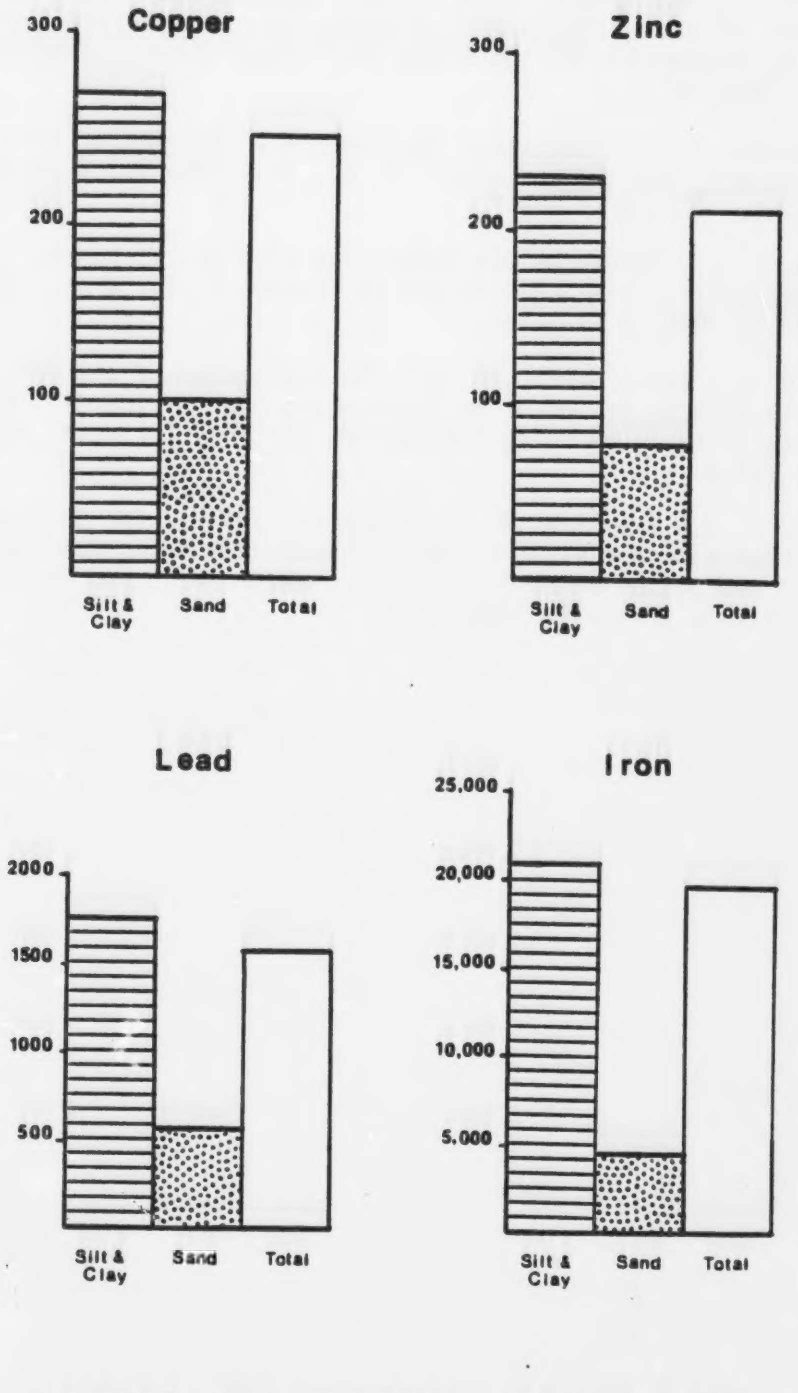

Figure 7. Mean concentration of metals in Lake Ellyn bottom sediments, by particle size. (Concentration in milligrams per kilogram.)

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DISTRIBUTION OF TOXICITY IN THE SEDIMENTS OF THE ILLINOIS WATERWAY

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INTRODUCTION

Benthic or bottom-dwelling organisms are key links in food chains leading from nutrients in the water and mud to higher level consumers such as fish and waterfowl, which in turn are utilized both recreationally and commercially by man. For example, Ranthum [1] and Jude [2] found that during certain times of the year fingernail clams (*Musculium transversum*), soft-shelled bivalves about the size of your fingernail, comprise up to 100% by volume of the diets of carp and smallmouth buffalo, both of which are commercial species. In the early 1900's a healthy benthic community contributed to the Illinois River's being second only to the Columbia in value of commercial fish catch from American rivers [3]. As densities of fingernail clams in the Illinois River declined, so did the commercial fish yields. Diets of the lesser scaup duck were found to consist of over 85% benthic mollusks [4]. As late as the 1940s the Illinois River Valley supported migrating populations of over 2 million of these diving ducks [5]. As the fingernail clams became scarce, so did the scaup [5].

Benthic filter feeders such as the fingernail clams also provide a mechanism for tertiary treatment of man's organic wastes, converting them from an oxygen demand problem into useable biomass. The quantity and quality of the benthic communities of the Illinois River Waterway have been greatly reduced by man's influences on the waterway, and with them those food chains and consumer organisms which are dependent on the bottom dwellers. Today's Illinois Waterway is a channel approximately 537 km (333 miles) long connecting Lake Michigan near Chicago with the Mississippi River near Grafton, Illinois, by way of the Calumet River and the Cal-Sag Channel, the Chicago River, the Chicago Sanitary and Ship Canal, the Des Plaines River, and the Illinois River (Figure 1). The U.S. Army Corps of Engineers maintains a minimum channel depth of 2.74 m (9ft) for navigation by dredging

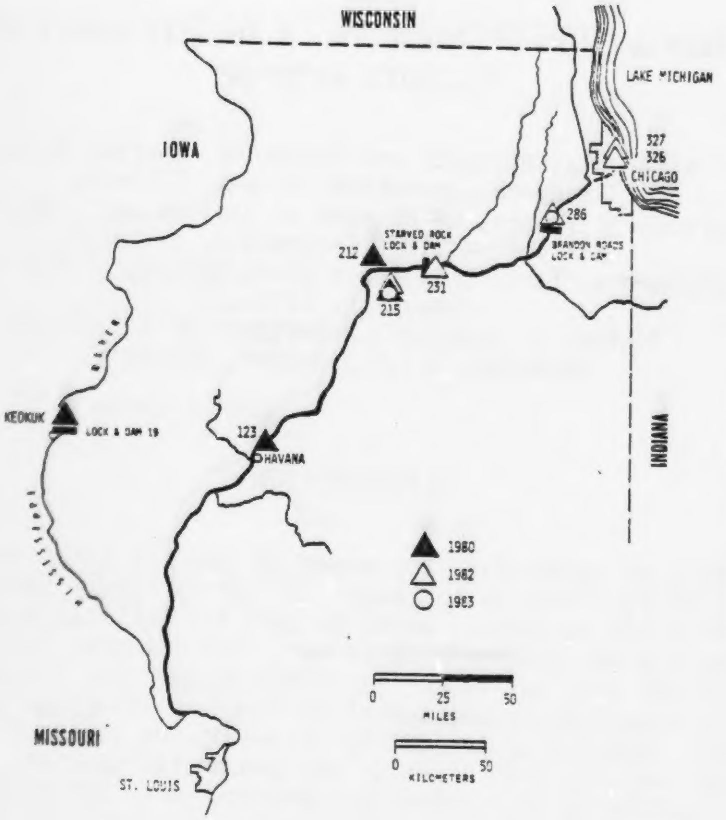
WISCONSIN
IOWA
LAKE MICHIGAN
327
326
CHICAGO
286
BRANDON ROADS LOCK & DAM
STARVED ROCK LOCK & DAM
212
231
215
KEOKUK
LOCK & DAM 19
RIVER
123
HAVANA
INDIANA
MISSISSIPPI
▲ 1980
△ 1982
○ 1983
0 25 50
MILES
0 50
KILOMETERS
MISSOURI
ST. LOUIS

Figure 1. Sediment Sampling Locations on the Illinois Waterway.

accumulated sediments as necessary and by regulation of water levels with locks and dams. The Illinois River has 8 such structures. Pools formed are named after the dam which retains them and are useful in denoting sections of the river. Locations on the waterway are also designated by river mile as found on river charts prepared by the U.S. Army Engineer District, Corps of Engineers [6]. River miles begin with mile zero at the confluence of the Illinois and Mississippi Rivers near Grafton, Illinois, and are numbered upstream consecutively. The Illinois River proper begins near river mile 273, which is the confluence of the Kankakee and Des Plaines Rivers.

In 1871, the flow of the Chicago River (which formerly flowed into Lake Michigan) was reversed to carry its load of untreated human sewage and industrial waste from Chicago's sewer system, away from the city's drinking water supply (the lake) and into the Des Plaines and Illinois Rivers by way of the Illinois and Michigan Canal (Figure 2).

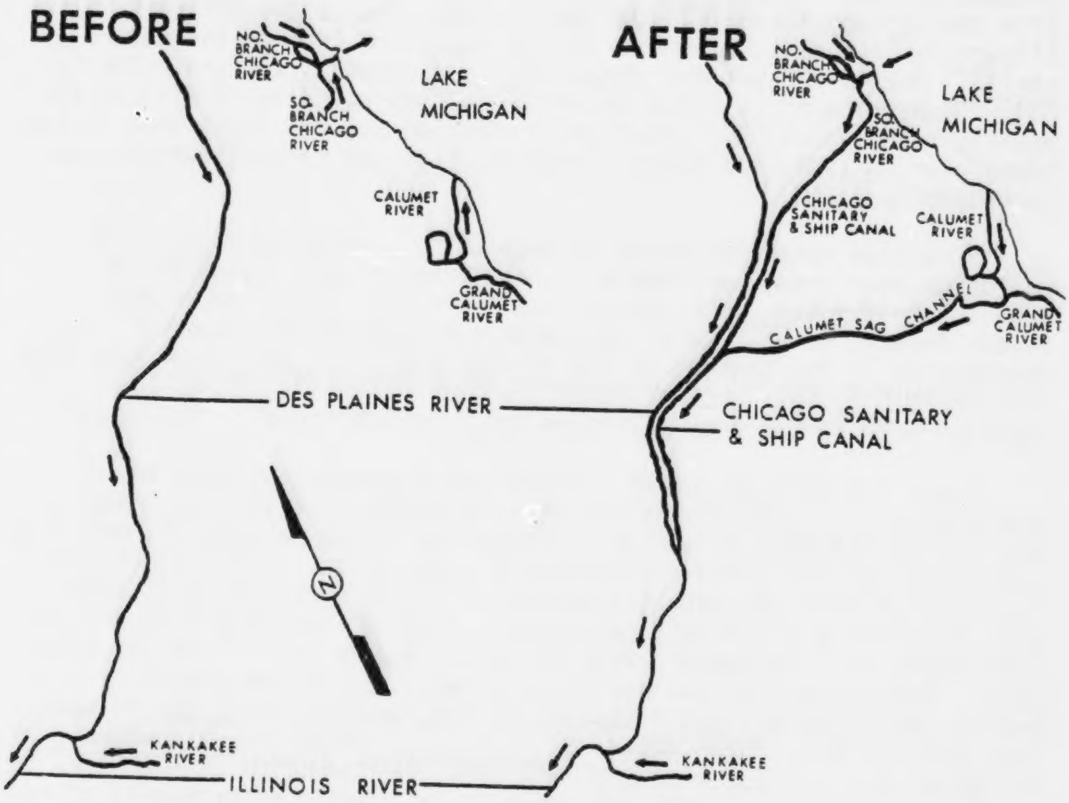
BEFORE
NO. BRANCH CHICAGO RIVER
SO. BRANCH CHICAGO RIVER
LAKE MICHIGAN
CALUMET RIVER
GRAND CALUMET RIVER
DES PLAINES RIVER
KANKAKEE RIVER
ILLINOIS RIVER
N
AFTER
NO. BRANCH CHICAGO RIVER
SO. BRANCH CHICAGO RIVER
LAKE MICHIGAN
CHICAGO SANITARY & SHIP CANAL
CALUMET RIVER
CALUMET SAG CHANNEL
GRAND CALUMET RIVER
CHICAGO SANITARY & SHIP CANAL
KANKAKEE RIVER

Figure 2. Flow Patterns Before and After Reversal of The Chicago River.

Note: The Illinois and Michigan Canal formerly flowed parallel to today's Chicago Sanitary and Ship Canal.

The U.S. Commissioner of Fish and Fisheries reported that the waste caused fish in the waterway to "bloat and float to the top" [7].

Flooding of the Chicago River and subsequent contamination of Lake Michigan waters prompted a new solution in the 1890's. In 1900, the Chicago Sanitary and Ship Canal was opened to allow diversion of large volumes of Lake Michigan water to dilute and transport untreated waste from the Chicago River into the Des Plaines, thence the Illinois (Figure 2). Short-term effects of the increased load on the waterway varied. Near the upper end oxygen levels dropped as did productivity [8]. Downstream of La Salle decomposed wastes acted as fertilizer for aquatic food chains [8]. Plankton production was 2-3 times what it had been prior to 1900, and Forbes suggested bass and carp fisheries rose correspondingly [8].

Diversion rates increased through 1912. Increased flow moved pollution downstream more rapidly, resulting in less digestion of organics by the time they reached the Illinois. Dissolved oxygen levels dropped to near zero. Richardson documented the ensuing degradation of the benthos in the middle section of the river from 1911 through 1920 [9,10]. "Clean water species" of snails, clams and mayflies were replaced by pollution tolerant tubificid "sewer worms".

Reduction of flow due to limitations on diversion rates and construction of large navigation dams, slackening of wartime industry and initial attempts at sewage treatment all played a part in improving conditions for the benthos in the 1920's and 30's. Little additional research was done on benthic communities of the waterway until 1952 when Paloumpis and Starrett found the bottom dwellers had recovered to some degree in 3 backwater lakes along the middle section of the river [11]. They documented another drastic reduction in the 1950's. Benthic densities dropped from over 25 thousand organisms per m^2 to less than 10 individuals per m^2 by 1956 [11]. Even though numbers recovered to some degree in 1957 and '58, they dwindled to near zero in ensuing years and have remained there since. Major constituents of the 1952 benthic community were the fingernail clams, especially the species *Musculium transversum*. These benthic organisms were once abundant or at least common in the waterway as far upstream as the Marseilles Dam (river mile 247). However, in his 1975 survey, Anderson found no fingernail clams at his sample stations upstream of river mile 107 [12].

Sparks, Paparo, Anderson, and others have directed extensive research at identifying factors which prevent these important links in aquatic food chains, and possibly other benthic organisms, from recolonizing areas of the waterway where they were once abundant [13, 14, 15, 16]. They found un-ionized ammonia concentrations in the water column sporadically exceeded those which reduced growth and survival of fingernail clams in the laboratory [12], but they also suspected that other factors toxic to the clams might occur in sediments.

In 1980 Sparks and Sandusky exposed *M. transversum* gills to sediments from 3 locations on the Illinois River where the clams were once abundant but are no longer found, and from one site on the

Mississippi River where they are still abundant (Figure 1) [16]. They measured the response of the beating and particle transport rates (of lateral cilia on the gills) to the sediments. This beating produces currents which move oxygenated water containing food particles through the clams. Reduction of beating inhibits the clams ability to acquire oxygen and organic matter needed for respiration, thus extended periods of reduction are fatal to the organisms. Previous research has shown a high correlation between short term bioassays measuring beating and transport rates and long-term laboratory bioassays [13, 14]. In general, sediments from the Illinois Waterway reduced beating and particle transport rates, while those from the Mississippi had little effect. Therefore, they concluded there is also a factor (or factors) in the Illinois Waterway sediments which prevents clam recolonization upstream of river mile 107. They also found that sediments from 2.6 - 5.1 cm of the surface reduced transport rates more than those from 0 - 2.5 or 5.2 - 10.2 cm from the surface, indicating a differential toxicity of layers of sediments.

Fingernail clams are not the only benthic organisms which show an upstream decrease in numbers and biomass. Anderson documented a similar trend in many other benthic invertebrate groups and found an upstream decrease in diversity as well [12].

In light of proposed increases in diversion of Lake Michigan waters, it was important that the distribution of toxicity in the sediments of the Illinois Waterway be determined. If sediments laid down since stringent pollution laws of the 1970's are less toxic than earlier deposits, scour from increased flow could expose the more toxic substrates. If sediments upstream, which originate primarily from municipal run-off from Chicago and Joliet [17], are more toxic than agricultural sediments downstream, such an increase could move the more toxic sediments downstream, extending the zone of benthic degradation.

MATERIALS AND METHODS

SEDIMENT SAMPLES

In 1982, we chose 5 sample locations along the upper Illinois Waterway where sediments were known or expected to accumulate (Figure 1). In upstream order they are: 1) Turner Lake, a backwater, waterfowl hunting area just adjacent and connected to the Illinois River near river mile 215, downstream of Spring Valley, 2) Starved Rock Pool upstream of Starved Rock Lock & Dam near river mile 231 on the Illinois, and close to North Utica, 3) a site at river mile 286 on the Des Plaines River above Brandon Road Lock and Dam at Joliet, 4 & 5) and two sites (river miles 326 and 327) on the North Branch of the Chicago River, downtown Chicago. During the summer of 1982 duplicate sediment cores were taken at the river mile 215, 231 and 286 sites, and single cores at the 326 and 327 sites.

Cores were obtained by forcing appropriate lengths of 7.5 cm diameter PVC pipe into the substrate from a boat. Once inserted, the pipe was stoppered and the sampler with intact core and water column was retrieved. It was placed with the stoppered end slightly below horizontal, and water was carefully drained. A ramrod was used to extrude the core onto a measuring board for observation. Cores were then sectioned into a surface layer 0 - 7.6 cm and a deep layer 22.9 - 30.5 cm from the surface. Each section was transferred to an individual 400-ml glass jar. Jars were sealed and number coded prior to being placed in a plastic cooler containing ice, or to which ice was added as soon as practical. Sediment samples remained on ice until shipped via air freight to the Dauphin Island Sea Lab, Dauphin Island, Alabama.

RAPID ASSESSMENT BIOASSAYS

Fingernail clams used in bioassays were collected as described by Anderson et al. [13] to insure compatability with the rapid bioassay they developed. All clams were taken from Keokuk Pool of the Mississippi River. We then used the clams to determine the relative toxicities of the sediment samples. Ten clams were removed from their shells for each sample tested. Five animals were pinned to a mat in a petri dish and used as an experimental preparation. The remaining 5 were prepared identically and used as a control. A known concentration of sediment was introduced into the experimental preparations, and yeast added to the controls. A continuous flow of standard invertebrate physiological solution, with added sediment or yeast, was maintained by metering pumps. Temperature, dissolved oxygen, and pH of the solutions were monitored and maintained as necessary throughout the tests.

Dual, coupled microscopes mounted on an aluminum scanning stage were used to simultaneously monitor the gill cilia in the experimental and control preparations. A calibrated strobscopic light served as a light source for both scopes by way of a silver coated, Y-shaped pyrex glass rod. The rate of beating of the lateral cilia was determined by manually synchronizing the rate of flashing of the light with the beating rate. The rate was then read from a digital readout. An average rate was determined for a field of 100 gill filaments for each of the 5 animals per sample. Rates were measured at 5 minute intervals for 30 minutes.

RESULTS AND DISCUSSION

CONTROL BIOASSAYS

Results of a total of 20 control tests with yeast suspensions (of particle concentration and size similar to sediment suspensions used as experimentals) showed a mean change in beating rate of 0 beats/sec, plus or minus a standard deviation of 1.25, after 30 minute exposures. Therefore, reduction of the rate in an experimental preparation was interpreted as a response to some toxicity in the sediments and not to test concentrations or conditions.

EXPERIMENTAL BIOASSAYS

Surficial sediments from the downstream site, river mile 215 which is Turner Lake, produced very little change in beating rate (Figure 3). Therefore we concluded that the samples showed little *relative* toxicity after 30 minutes. It is important to note that previous experiments have shown the Turner Lake sediments to be toxic during longer exposures [16]. Surficial sediments from the mile 231 sample site, just above Starved Rock Lock and Dam, caused a

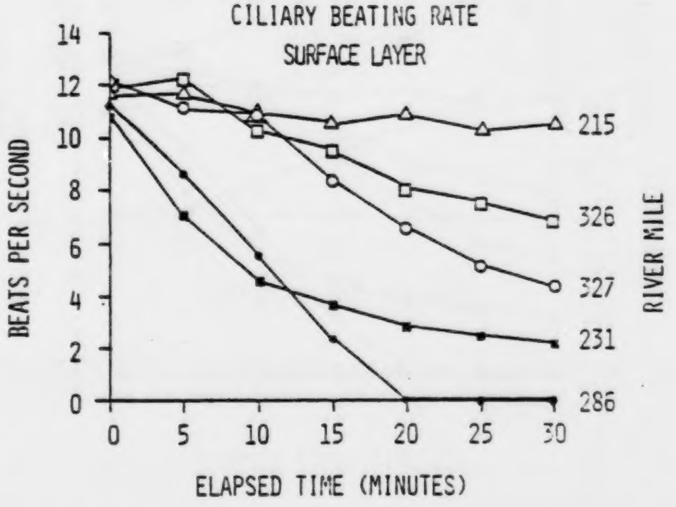

Figure 3. Cilia Beating Rates Resulting from Exposure to Surface Sediments from 5 Locations on the Illinois Waterway.

significant drop in beating. Therefore, those samples were more toxic than the previous. Samples from above Brandon Road Lock and Dam near river mile 286 appeared to be the most toxic surficial sediments. Complete ciliary arrest was obtained by the 20-minute observation. Sediments from the Chicago River sites at river miles 326 and 327 were apparently less toxic, falling somewhere between the Turner Lake and Starved Rock sediments in toxicity. We obtained similar results for the deep layer sediments (Figure 4). Once again sediments from the site at mile 215 produced little drop in the beating rate after 30 minutes. Those from Starved Rock at mile 231 caused a significant depression. As before sediment from Brandon Road at river mile 286 or caused complete ciliary arrest, in one sample in less than 10 minutes. These results suggest an upstream increase in toxicity of Illinois Waterway sediments at least as far as Brandon Road Lock and Dam near Joliet (river mile 286).

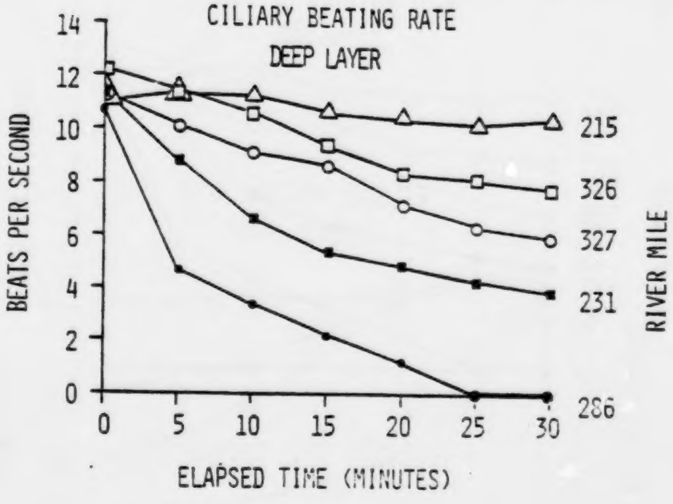

Figure 4. Cilia Beating Rates Resulting from Exposure to Deep Sediments from 5 Locations on the Illinois Waterway.

This upstream augmentation in sediment toxicity can be seen more readily from a histogram showing percent depression of the metachronal beating rate after 30-minute exposure to sediments (Figure 5). Percent depression was determined by the formula:

$$D = ((R_i - R_f)/R) \times 100\%$$

where: D = percent depression
R_i = initial rate(time = 0 minutes)
R_f = final rate(time = 30 minutes)

In both the surface and deep layers of sediments we see this upstream increase in sediment toxicity as far as river mile 286. Sediments from sample sites near river miles 326 and 327, on the North Branch of

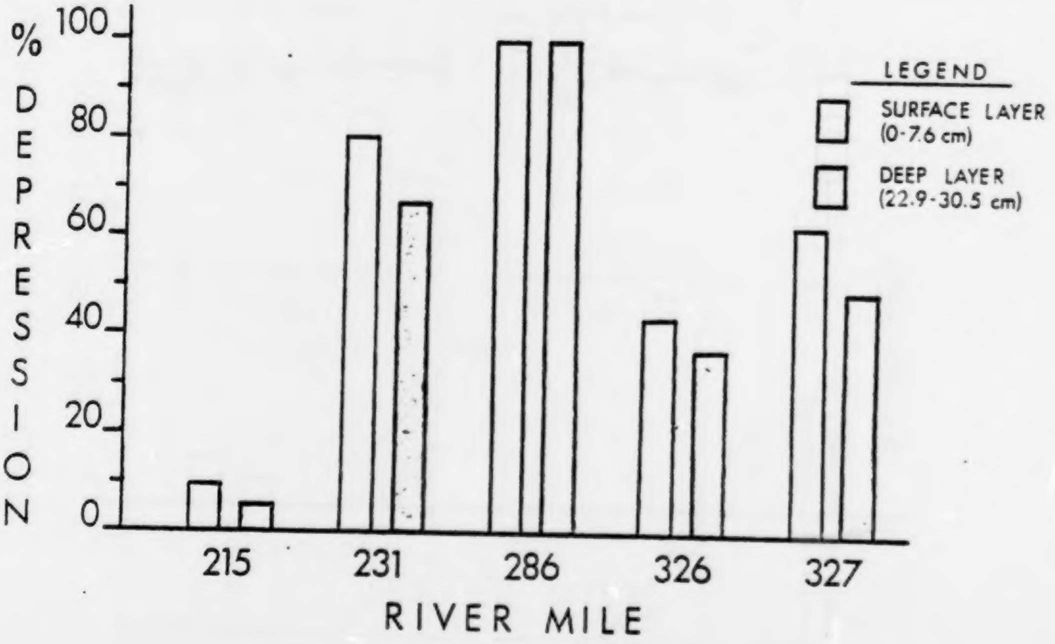

Figure 5. Percent Depression of Beating Rates Resulting from 30 Minute Exposure to Sediments from 5 Locations on the Illinois Waterway.

the Chicago River, were upstream of the mile 286 site but appeared to be less toxic. In all samples except river mile 286 (Brandon Road) the percent depression after 30 minutes was greater for the surficial layer sediments than for the deep layer, although differences were not significant. Both layers from river mile 286 showed complete or 100% ciliary arrest of normal beating within 30 minutes of exposure.

In 1983 we returned to the least toxic (river mile 215) and most toxic (river mile 286) sites to verify previous results, and in conjunction with the Geological Survey, to determine concentrations of heavy metals in the sediments. A single core was taken at both sites and sectioned into a surface and deep layer as in 1982 and bioassays were rerun. Results of the 1983 bioassasys were compared with those of 1982 and were remarkably consistent for the most part (Figure 6). In some cases there was more difference between results from adjacent samples taken at the same time than between those taken in different years.

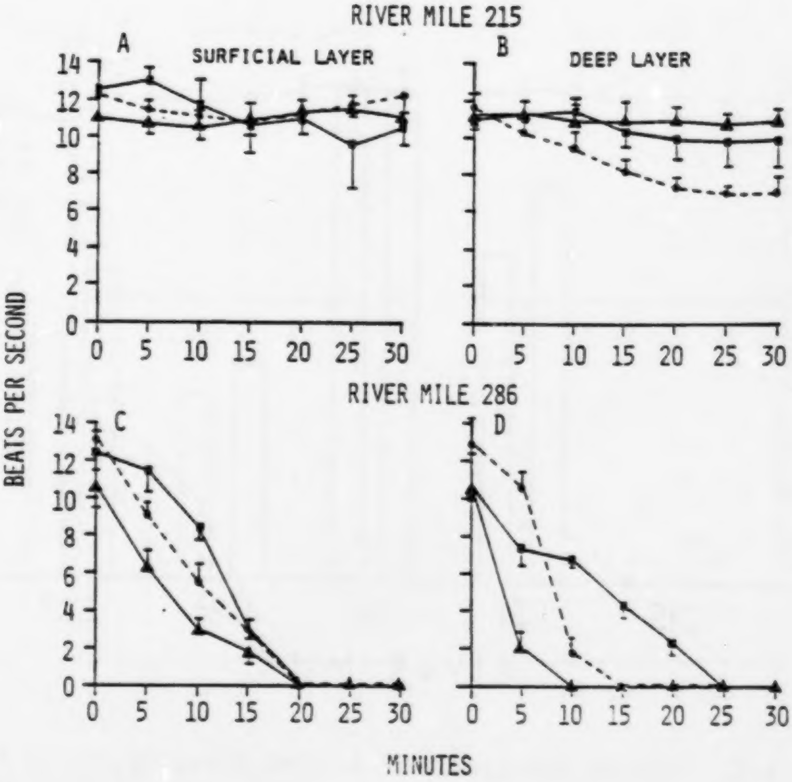

Figure 6. Comparison of Beating Rates Resulting from Sediment Samples Taken in 1982 with Those from Samples Taken in 1983.

CHEMICAL ANALYSIS

Chemical analysis of 3 sediment layers from the most toxic site (river mile 286) and the least toxic site (river mile 215) showed concentrations of 10 metals were significantly higher in sediments which had shown maximum toxicity (Table 1). Such an upstream increase in metal concentrations in sediments has been described [18, 19, 20]. There were no significant correlations between concentrations and layer depth at either site. Availability of heavy metals in sediments for uptake by benthic organisms has not been determined, and no causal relationship has been shown between the elevated metal levels and toxicity of the sediments. However, Anderson [21] and Mathis and Cummings [22] found that metal concentrations in benthic organisms can be more representative of concentrations in sediments than of concentrations in the water column.

Table 1: Concentrations (ppm) of Heavy Metals in Sediments from Turner Lake (River Mile 215) and the Des Plaines River near Brandon Road Lock and Dam (River Mile 286).

Depth (cm)	Location	Pb	Zn	Cd	Ag	Sn	Cr	Ni	Cr	As	Sb
0-7.6	T	60	242	1.6	<1	<5	60	30	112	11	1.5
	B	609	2627	64.0	12	31	453	220	670	24	13.0
7.6-22.9	T	65	265	2.5	<1	<5	68	40	110	11	1.4
	B	435	1695	37.0	6	22	324	299	454	16	9.0
30.5-45.7	T	80	328	4.3	<1	<5	63	41	135	11	1.7
	B	738	2330	73.0	12	34	500	284	700	16	14.0

T = Turner Lake
B = Brandon Road

CONCLUSIONS

A toxic substance, associated with sediment, was or is introduced to the Illinois Waterway upstream of mile 286 and is detectable at least as far downstream as mile 231. Since deeper layers of sediment are not significantly less toxic than more recently deposited surficial layers, it is probable that the toxicant is currently being introduced. It has produced an upstream increase in sediment toxicity, and is probably a factor contributing to the upstream decrease in benthic biomass and diversity described by Anderson [12]. If the origin of toxicant is a point source between river miles 286 and 326, sediment on the North Branch (river mile 326 and 327 sites) should not be affected as flow would move the contaminant downstream. Reductions produced by North Branch sediments may be due to a toxic factor different from that causing the toxicity at the 286 site. If the toxic substance was entering the waterway from a nonpoint source, such as urban run-off from the Chicago-Joliet metropolitan complex, sediments near the upstream end of the area could be toxic, but less so than those downstream, as was the case in this study.

In 1976, Briceland [23] stated that over 4 billion dollars had been spent since the mid 60's on waste treatment by municipalities in the Illinois River drainage basin, primarily in the Chicago, Joliet and Peoria areas, and yet no noticable recovery of the mud-dwelling benthic community has occurred. There is only marginal hope of solving the toxic sediment problem until the identity of the factor or factors responsible for preventing the recovery in the mud-dwelling benthos is solved. This could be done by chemical fractionation of sediments and direct biological testing of the fractions using a technique similar to that used by Samoiloff et al. [24] on sediments from Tobin Lake, Saskatchewan.

Unless the benthos is restored there is no hope of reestablishing the diving duck populations and commerical fisheries that once existed on the waterway. As long as sediments of the upper Illinois Waterway are toxic increased diversion will hold the threat of moving this unknown toxicant downstream, further degrading or destroying important benthic communities. Sediments in the upper waterway orginate primarily from municipal run-off [17]. It is important that the quality of these inputs be controlled. Hopefully the degradation of benthic communities and resulting loss of commercial and recreational opportunities which has persisted in the Illinois Waterway will be a lesson that will not have to be relearned elsewhere.

ACKNOWLEDGEMENTS

The Illinois Natural History Survey River Research Laboratory, Havana, Illinois, received support for this study from the Chicago District of the U.S. Army Corps of Engineers, as part of a larger project to determine possible effects of increased diversion of Lake Michigan waters into the Illinois Waterway. We are grateful to Katie Roat who typed this manuscript.

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- NOTES -

CLOSING SESSION

THE USEPA OFFICE OF RESEARCH AND DEVELOPMENT'S VIEW OF COMBINED SEWER OVERFLOW CONTROL

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INTRODUCTION

The mission of the Storm and Combined Sewer Program (SCSP) is to develop methods for controlling pollution from urban storm water dicharges and combined sewer overflows (CSO), and excessive inflow and infiltration (I/I). Since this session is on CSO, research relevant to CSO will be emphasized.

The Program has been involved in the development of a diverse technology including such things as CSO and storm water control technology, instrumentation, problem assessments, best management practices (BMP) development and evaluation, storm water management models, sludge handling and disposal methods, I/I control, erosion control, and many others. This presentation will cover SCSP products and accomplishments in these areas since Program origin, 18 years ago. The time alloted will not allow complete coverage. Therefore emphasis will be more on recent developments.

POLLUTION PROBLEM ASSESSMENT

Characterization

The quality and quantity characterization of CSO is necessary for problem assessment, planning, and design. Summaries of characterization data from many research studies are available (1-3). The average pollutant concentrations for urban runoff and CSO are compared to background pollution and sanitary sewage in Table 1.

Since 1974, we supported the urban rainfall-runoff-quality data base (4,5) for two important data requirements: characterization, and calibration and verification of models. This project was initiated to bring together the many widely scattered data sources.

From an in-house project, preliminary screening of urban wet-weather discharges from 24 samples from nine urban areas found approximately one-half of the 129 priority pollutants (Table 2). The heavy metals were consistently found in all samples. Polynuclear aromatic hydrocarbons from petroleum were the most frequently detected organics followed (in order) by phtalate esters, aromatic hydrocarbons, halogenated hydrocarbons, and phenols.

Table 1. Comparison Of Typical Values For Stormwater Discharges[a]

	TSS	VSS	BOD	COD	Kjeldahl Nitrogen	Total Nitrogen	Total PO_4-P	OPO_4-P	Lead	Fecal Coliforms
Background Levels	5-100	-	0.5-3	20	-	0.05-0.5[b]	0.01-0.2[c]	-	<0.1	-
Stormwater Runoff	415	90	20	115	1.4	3.10	0.6	0.4	0.35	13 500
Combined Sewer Overflow	370	140	115	367	3.8	9.10	1.9	1.0	0.37	670 000
Sanitary Sewage	200	150	200	500	40	40	10	7	-	-

a. All values mg/l except fecal coliforms which are organisms/100 ml.

b. NO_3 as N.

c. Total phosphorus as P.

Table 2. Distribution of Priority Pollutants Frequently Detected

Pollutant	Frequency*		Range**	
	Liquid	Sediment	Liquid (μg/l)	Sediment (μg/kg)
Phenols	6	-	0.3-0.9	-
Polynuclear Aromatic Hydrocarbons (PAH's)				
Fluoranthene	5	3	0-98	1,200-4,000
Pyrene	4	3	0-76	1,200-3,000
Anthracene	-	3	-	375-7,000
1,2-Benzanthracene	-	2	-	1,100-4,100
Benzo(a)pyrene	-	2	-	600-25,000
3,4-Benzofluoranthene +	-	2	-	2,800-4,600
11,12-Benzofluoranthene	-	-	-	-
Chrysene	-	2	-	1,500-4,100
Fluorene	-	2	-	210-300
Phenanthrene	-	2	-	375-2,000
Esters				
Bis(2-ethylhexyl)phthalate	6	3	0-160	130-59,000
Di-n-butyl phthalate	6	3	0.5-3.4	300-25,000
Butylbenzyl phthalate	-	2	-	450-1,200
Heavy Metals				Sediment (mg/kg)
Arsenic	7	3	2-15	2.8-4.8
Beryllium	7	3	1-2	0.1-0.2
Cadmium	7	3	2-7	0.06-1
Chromium	7	3	9-36	8.10-28
Copper	7	3	11-49	7-140
Lead	7	3	30-400	24-370
Nickel	7	3	9-40	3-16
Silver	7	3	3-8	0.5-2.1
Zinc	7	3	90-330	37-380
Antimony	7	3	<20	3-3.3
Selenium	7	3	3-10	0.06-1.4
Thallium	7	3	2-10	<0.2
Mercury	7	3	0.2-0.56	2.1-2.4

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*Reported when found four or more times out of seven liquid samples and two or more out of three sediment samples.

**These are mostly grab samples and therefore cannot be accurately related to pounds of pollutants discharged. Also, the mass emission of pollutants will vary for each rainfall event.

A project in Syracuse, New York used the Ames test to evaluate urban runoff and CSO mutagenicity (6,7). Detectable responses have been obtained on 22 percent of the samples. It is significant that some mutagenic substances are present with a potential for entering the food chain.

Indicators such as fecal coliform have long been known to be present in storm water discharges in densities sufficient to cause contravention of standards. A study in Baltimore, Maryland identified actual pathogens and enteroviruses in storm sewer discharges (8). Cross-connections from sanitary sewers were strongly implicated as the major cause. Obviously, this problem is not isolated to Baltimore. For instance, two surveys in Canada found that 13 and 5 percent of the houses had illicit sanitary connections to storm sewers, respectively.

Receiving Water Impacts

Knowledge of the receiving water impacts resulting from urban wet-weather discharges is a basis for determining the severity of problems and for justifying control. Program studies of receiving water impacts are described in a proceedings from a national conference (9) and in a journal paper (10).

Under certain conditions, storm runoff can govern the quality of receiving waters regardless of the level of dry-weather flow treatment provided. Based on national annual mass balance determinations, urban wet-weather oxygen demand loads are greater than the dry-weather loads from the same areas (11,12). Hence, control of runoff pollution can be a viable alternative for maintaining receiving water quality standards.

The SCSP has had only partial success in finding urban storm flow generated receiving water impacts employing the conventional dissolved oxygen (DO) (10,13). The problem appears to be in the application of conventional dry-weather monitoring in unsteady-state flow regimes caused by storms. Further studies should be undertaken to resolve the anomaly between actual runoff loadings and observed receiving water impacts. The Program has been more successful in sediment analysis than in water column analysis for DO depletions. Direct evidence has been obtained (from the Milwaukee River project (14)) of how a disturbed benthos depletes DO from the overlying waters. Studies have also shown that storm and CSO adversely affect sediment by toxics enrichment and resultant biological upsets (9,10,15-17). Since particulate matter in untreated storm and CSO is larger, heavier, and in signficant quantities when compared to treated sanitary effluent, more needs to be known about the fate and transport of settleable and separable materials. Hydrodynamic solids separation and sediment transport routines must be added to receiving water models to take care of the neglected or presently omitted significant particulate and bed flow fields.

A simplified continuous receiving water quality model has been developed for preliminary planning and screening of areawide wastewater treatment alternatives in terms of frequency of water quality violations (18,19). Also, a general methodology has been developed for evaluating the impact of CSO's on receiving waters and for determining the abatement costs for achieving various water quality goals (20). In addition, a methodology for defining criteria for wet-weather quality standards has been developed (21-23). In recognition of an important gap in the developed methodologies, the duration of water quality standards vs. species survival was taken into consideration.

USER'S ASSISTANCE TOOLS

User's assistance tools include instrumentation, storm water management models, manuals of practice (MOP), methodologies, compendiums, and state-of-the-art (SOTA) reports.

Instrumentation

Storm flow measurement is essential for process planning, design, control, evaluation, and enforcement. Sampling devices do not provide representative aliquots. Conventional flowmeters apply to steady-state flows and not to the highly varying storm flows.

Flowmeters have been developed to overcome these adverse storm conditions (24,25). A prototype sampler for capturing representative solids in storm flow has also been developed and a design manual is available (26). This gave manufacturers the incentive to perfect samplers by increasing intake velocities and other ways. SOTA's are available for flow measurement and sampling (27,28). Because storm flow conditions are extremely adverse, the manuals and instruments developed are useful for monitoring all types of flow.

Simulation Models

The Program has fostered the development of models for assessment, planning, design, and control of urban storm water pollution. Program thinking on urban water management analysis involves four levels of evaluation ranging from simple to complex, that can be worked together.

The various levels of the Storm Water Management Model (SWMM) are the most significant model products in terms of past resources and overall popularity. SWMM is one of the most widely used urban models and its benefits for planning and design have been demonstrated. It has been employed by consulting engineers to design sewers and to analyze pollution control alternatives.

There are significant recent enhancements of SWMM. Probably the most significant is Version III (29-31) which includes: better documentation and improved stability of the dynamic flow routing model, EXTRAN;

documentation of continuous simulation and snowmelt capabilities; new flexible physically-based storage and treatment routines which can provide estimates of treatment (by settling) in storage basins; an addition of the physically-based Green Ampt infiltration model; and flexible quality routines and other routines.

Documentation and user's manuals are also available for three continuous storm water planning models. One is a detailed model, the Quantity-Quality Simulation model (QQS) (32,33). The other two are macroscopic planning models, ABMAC (34,35) and EPAMAC (36,37). ABMAC is a regional preliminary planning model which employs a daily time step, and EPAMAC is a continuous model employing an hourly time step for planning in the context of a 201 Step I Facility Plan for CSO control. Functionally, it is similar to the Storage, Treatment, Overflow, and Runoff Model (STORM); however, the storage configurations are much more flexible and include sedimentation effectiveness and the model is applicable specifically for metropolitan-scale applications.

Operational models which have been implemented in Detroit (38), Minneapolis (39), Seattle (40), and San Francisco produce control decisions during storm events.

SOLUTION METHODOLOGY

A major emphasis of the Program was solution methodology, through developments of SOTA reports, MOP's, and user's manuals.

The SOTA texts, user's guide and the assessment on urban stormwater technology are excellent documents (41,42). Separate engineering manuals are available for storm flow rate determination (43,44), porous pavement design (45-48), cost estimating (49-51), storm sewer design (52-54), planning and design guidance (55), and for conducting stormwater studies (56). Seminar proceedings with themes of "modeling, design, operation, and costs," have been published.

The SOTA document on particle size and settling velocity (57) offers significant information for solids treatability and their settlement in receiving waters, important areas overlooked in planning and design. An excellent film is being distributed by the General Services Administration (GSA) National Audio Visual Center which covers the USEPA CSO Program, and in particular full-scale control technologies (58).

A report entitled, "Urban Stormwater Management and Technology: Case Histories," (59) presents 12 case histories which represent the most promising approaches to CSO and stormwater control. The case histories were developed by evaluating operational facilities that have significant information for future guidance.

Three illustrative methodologies for conducting CSO facility planning have been published (60-62).

MANAGEMENT ALTERNATIVES

The next major Program area is management alternatives. First is the choice of where to attack the problem; at the source by land management, in the collection system, or off-line by storage. We can remove pollutants by treatment and by employing integrated systems combining control and treatment.

Land Management

Land management includes structural, semi-structural and non-structural measures for reducing urban and construction site storm water runoff and pollutants before they enter the downstream drainage system. Various concepts have been fostered by the SCSP including:

- Land use planning;
- Natural drainage which will reduce drainage costs and pollution, and enhance aesthetics, groundwater supplies, and flood protection; and
- Retention and drainage facilities, and other management techniques required for flood and erosion control which can be simultaneously designed for pollution control.

Retention on-site or upstream can provide for multi-benefits of aesthetics, recreation, recharge, irrigation, or other uses.

Porous Pavement

Porous pavements provide storage, enhancing soil infiltration that can be used to reduce runoff and CSO. Porous asphalt-concrete pavements can be underlain by a gravel base course with whatever storage capacity is desired (Figure 1).

Results from a study in Rochester, New York, indicated that peak runoff rates were reduced as much as 83 percent (63). The structural integrity of the porous pavement was not impaired by heavy load vehicles. Clogging did result from sediment from adjacent land areas during construction; however, it was relieved from cleaning by flushing. The construction cost of a porous pavement parking lot is about equal to that of a conventional paved lot with storm water inlets and subsurface piping.

A project in Austin, Texas developed design criteria for porous pavements (46) and compared porous asphalt pavement to six other conventional and experimental pavements (47,48).

Surface Sanitation

Maintaining and cleaning urban areas can have a significant impact on the quantity of pollutants washed off by storm water.

Tests under real world conditions in San Jose, California showed that street cleaning can remove up to 50 percent of the total solids and heavy metal yields in urban stormwater with once or twice a day cleaning (64). Typical street cleaning programs of once or twice a month proved ineffective. Organics and nutrients could not be effectively controlled even with intensive cleaning.

In Bellevue, Washington, street cleaning proved ineffective; however, a modified regenerative air Tymco street cleaner showed promise (65,66). Street cleaning is no panacea for storm water pollution control (and is site specific dependent upon climatic conditions), but if integrated with other methods, could reduce city-wide costs.

Collection System Controls

The next overall Program category, collection system controls, pertains to management alternatives for wastewater interception and transport. These include: sewer separation; improved maintenance and design of catchbasins, sewers, regulators and tide gates; and remote flow monitoring and control. The emphasis with the exception of sewer separation is an optimum use of existing facilities and fully automated control.

Catchbasins

In a project conducted in Boston, Massachusetts, catchbasins were shown to be potentially quite effective for solids retention (60-97 percent) (67,68). Removals of associated pollutants such as chemical oxygen demand (COD) and biochemical oxygen demand (BOD), were also significant (10-56 percent and 54-88 percent, respectively). To maintain the effectiveness of catchbasins for pollutant removal requires cleaning probably twice a year depending upon conditions.

Sewers

Manuals on new sewer design to alleviate sedimentation and resultant first-flush pollution and premature bypassing (52), and sewer design for added CSO storage (54) are available.

Sewer Flushing

As a follow-up to an earlier study (69), providing simple equations for predicting dry-weather deposition in sewers, a report was published showing that flush waves can effectively convey sewer deposits including organic matter (70). In another study (71), it was concluded that sewer flushing could reduce CSO control costs seven percent when compared to a CSO storage/treatment treatment and disinfection facility designed for a one-year storm.

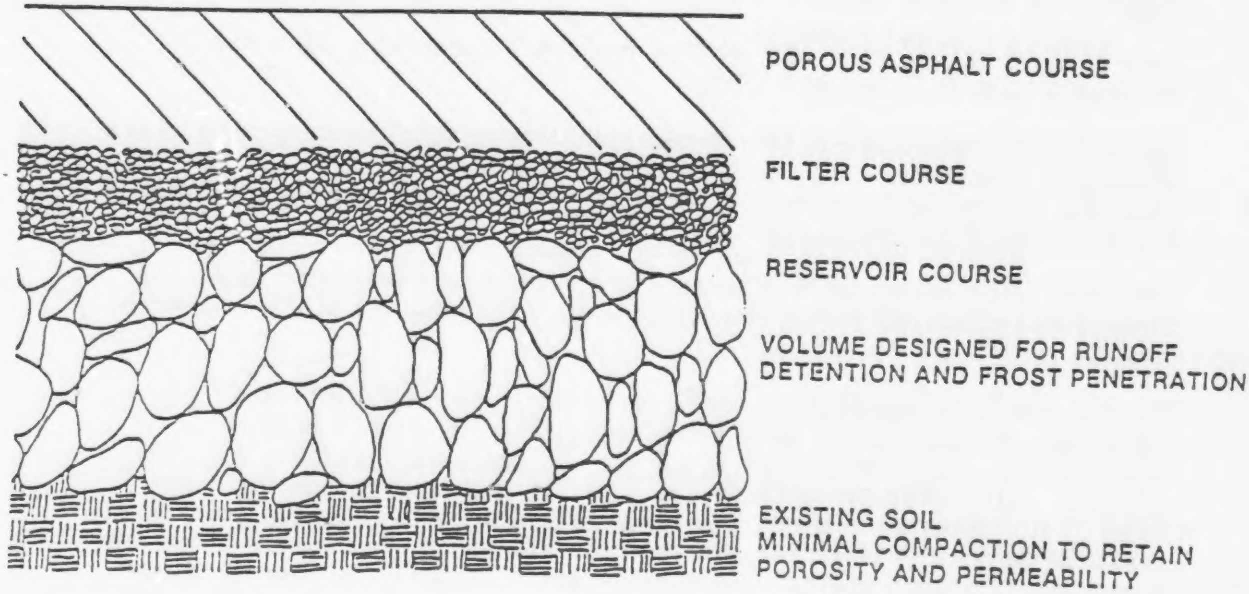

POROUS ASPHALT COURSE
FILTER COURSE
RESERVOIR COURSE
VOLUME DESIGNED FOR RUNOFF DETENTION AND FROST PENETRATION
EXISTING SOIL
MINIMAL COMPACTION TO RETAIN POROSITY AND PERMEABILITY

Figure 1. Porous Asphalt Paving Typical Section

Polymer to Increase Capacity

Research has shown that polymeric injection can greatly increase flow capacity and thus be used to correct pollution-causing conditions such as localized flooding and excessive overflows (72). Direct cost savings are realized by eliminating relief sewer construction.

Flow Routing

Another control method is in-sewer storage and routing to maximize use of existing sewer capacity. The general approach comprises remote monitoring of rainfall, flow levels, and sometimes quality, at selected locations in the network, together with a centrally computerized console for positive regulation. This concept has proven effective in New York, New York; Detroit, Michigan; (38) Seattle, Washington (40). Cleveland, Ohio; and San Francisco, California have also implemented this concept. Other cities are considering its use.

Regulators and Ride Gates

Pace setters in the area of overflow regulator technology were the Program's SOTA (73) and MOP (74).

Conventional regulators malfunction, lack flow-control ability, and cause excessive overflows. New devices such as the fluidic regulator, and the positive control gate regulator, have been demonstrated in Philadelphia, Pennsylvania (75), and Seattle, Washington (40), respectively.

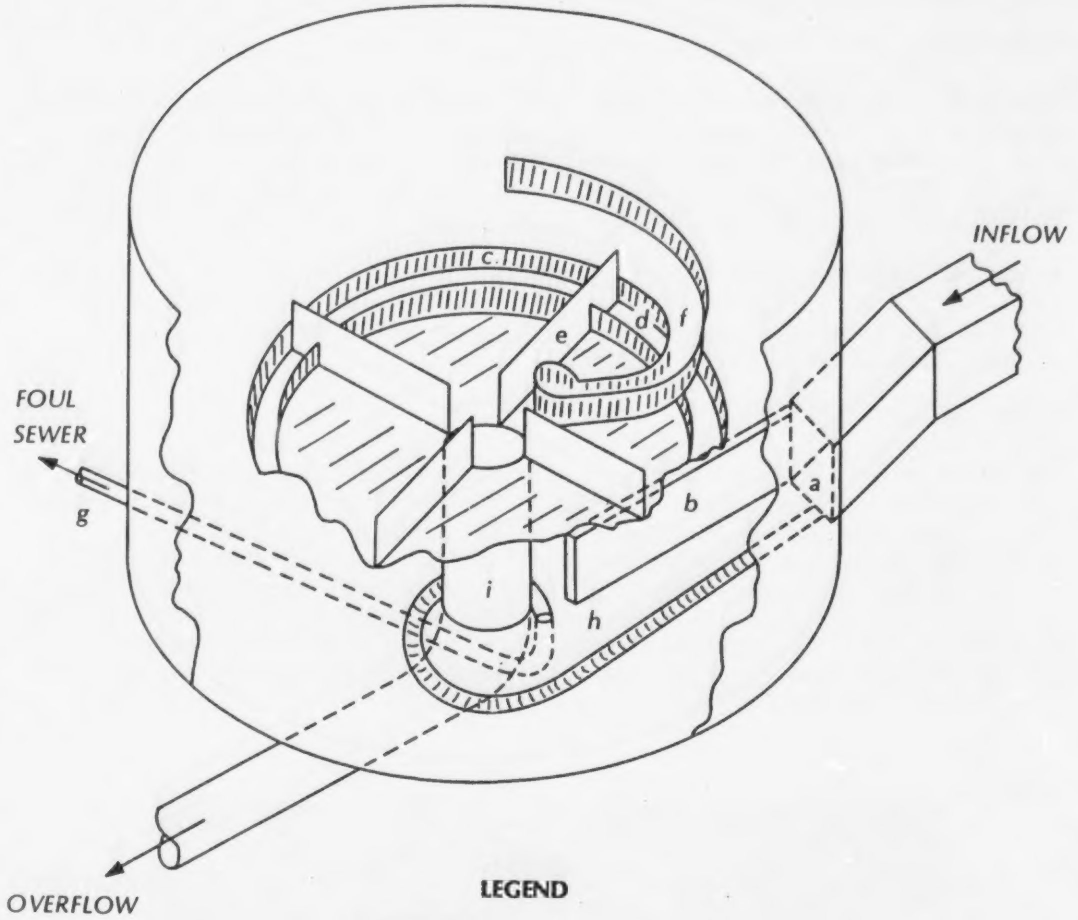
The dual functioning swirl flow regulator/solids concentrator (SRC) has shown outstanding potential for simultaneous quality and quantity control (76,77).

The SRC has been demonstrated for CSO in Syracuse, New York, and Lancaster, Pennsylvania. The device (Figure 2) of simple annular construction, requires no moving parts. It controls flow by a central circular weir, while simultaneously treating combined wastewater by a "swirl" action which imparts liquid-solids separation. Tests indicate at least 50 percent removal for suspended solids and BOD. Table 3 shows the Syracuse prototype results. Tankage is small compared to sedimentation making the device highly cost-effective.

A helical type regulatory/separator has also been developed based on principles similar to the swirl. A complete swirl/helical design textbook has been published (78).

Hydrobrakes

We have demonstrated Hydrobrakes in Rochester, New York (63) and Cleveland, Ohio (79,80). Hydrobrakes have no moving parts, require no external energy source to operate and are not susceptible to blockages.


INFLOW
c
e
d
f
FOUL
SEWER
g
a
b
i
h
OVERFLOW

LEGEND

a Inlet ramp
b Flow deflector
c Scum ring
d Overflow weir and weir plate
e Spoilers
f Floatables trap
g Foul sewer outlet
h Floor gutters
i Downshaft

Figure 2. Swirl Flow Regulator/Solids Concentrator

They can be used as upstream off-line flow attenuators, in-line flow back-up devices and as CSO regulators. Conceptually they allow flow release without orifice movement or closure at a constant perdetermined rate regardless of upstream head.

Tide Gate

Figure 3 shows a prototype rubber "duck bill" tide gate. The prevailing problems with conventional flap type gates is their failure to close tight and the need for constant maintenance. Poor tide gate performance results in higher treatment costs, treatment plant upsets, and greater pollutional loads due to downstream overflows and plant bypassing (81).

A project with New York City will demonstrate the "duck bill" tide gate (81). It is a totally passive device, requiring no outside energy to operate and apparently would be virtually maintenance-free, yet seal tightly around large solid objects.

Maintenance

The Program has fostered concepts for improved sewerage system inspection and maintenance emphasizing that it is absolutely necessary for a total system approach to municipal water pollution control. Premature overflows and backwater intrusion during dry as well as wet weather caused by malfunctioning regulators and tide gates, improper diversion settings, and partially blocked interceptors can thus be alleviated. The resulting pollution abatement obtained is a dual benefit of required system maintenance. Some cities have adopted this approach and have gained high CSO control cost benefits.

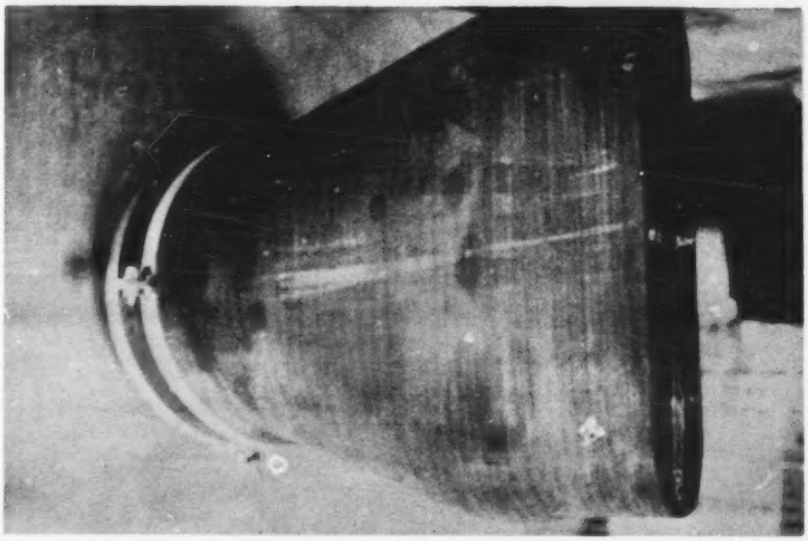


Figure 3. Prototype Rubber "Duck-Bill" Tide Gate

Table 3. Swirl Regulator/Concentrator Suspended Solid Removal, Syracuse, New York Prototype Results

Mass Loading (KG) Per Storm			Average SS Per Storm (MG/L)		
INF.	EFF.	Removal	INF.	EFF.	Removal
374	179	52%	535	345	36%
103	24	77%	374	165	55%
463	167	64%	342	202	41%

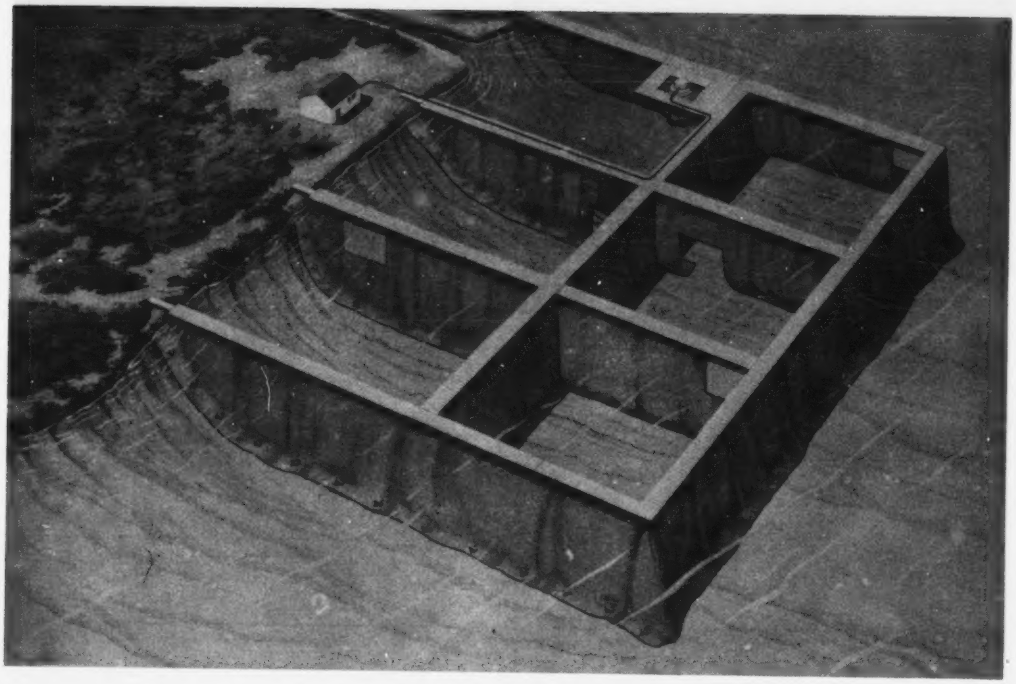


Figure 4. In-receiving Water Flow Balance Method.

Storage

Because of the high volume and variability associated with storm flow, storage is considered a necessary control alternative. It is the Program's best documented abatement measure. Project results and theory indicate storage must be considered at all times in system planning, because it allows for maximum use of existing dry-weather and other treatment plant facilities and results in the lowest cost in terms of pollutant removal.

Storage facilities may be constructed in-line or off-line, they may be open or closed, they may be constructed inland and upstream, on the shoreline, or in the receiving water; they may have auxiliary functions, such as sedimentation treatment, flood protection, sewer relief, flow transmission, and dry-weather flow equalization.

Storage concepts investigated include the conventional concrete holding tanks and earthen basins, and the minimum land requirement concepts of: tunnels, underground and underwater containers, underground "silos," natural and mined under and above ground formations, and the use of abandoned facilities and existing sewer lines (82,83).

The in-receiving water flow balance method (Figure 4), is a recently developed storage alternative (84). In-receiving water storage facilities contain CSO or (storm water) between floating plastic curtains. After cessation of the overflow, pumps start automatically and the surrounding waterbody will enter the compartments and push the storm flow back towards the first compartment where it is pumped to the plant. Thus, the waterbody is used as a flow balance medium.

The storage method is low-cost, due to the employment of low-cost materials (plastic and wood), the time required to install the unit (several days to months vs. months to a year), and the absence of land requirements. Studies show that costs could be about 5 to 15 percent of conventional concrete tank costs.

The facility which was tested at three locations in Sweden performed very satisfactorily, and was able to take ice and wind loads without adverse impact. It is desirable to demonstrate a facility in a harsh urban estuarine or marine site, such as the SCSP project will be doing shortly in Fresh Creek Basin in New York City, New York.

A storage/sedimentation planning/design manual (85) is being finalized which includes the following:

Major Issues

- Applicability,
- Integration into existing treatment system,
- Costs,
- Effectiveness as treatment/control device.

Secondary Issues

- Citing impacts,
- O&M Requirements,
- Sludge production and handling.

Treatment

Due to adverse and intense flow conditions and unpredictable shock loading effects, it has been difficult to adapt existing treatment methods to storm-generated overflows, especially the microorganism dependent biological processes. Physical/chemical treatment techniques have shown more promise than biological processes in overcoming storm shock loading effects. To reduce capital investments, projects have been directed towards high-rate operations approaching maximum loading.

Storm flow treatment methods demonstrated by the Program include physical, physical-chemical, wetlands, biological, and disinfection (86). These processes, or combinations of these processes, can be adjuncts to the existing sanitary plant or serve as remote satellite facilities at the outfall.

Physical/Chemical Treatment

Physical processes with or without chemicals, such as: fine screens, swirl degritters, high-rate filters (HRF), sedimentation, and dissolved air flotation (DAF), have been successfully demonstrated. Physical processes have shown importance for storm flow treatment because they are adaptable to automated operation, rapid startup and shutdown, high-rate operation, and resistance to shock loads.

The SCSP thinks that the high-rate processes: DAF, fine mesh screening, and HRF are ready for municipal installation.

The microstrainer conventionally designed for polishing secondary sewage plant effluent, has successfully been applied to CSO's and high-rate applications have given SS removals higher than 90 percent (87).

Full-scale microscreening units were demonstrated in two locations. In Syracuse, New York, SS removals of about 50 percent were achieved (88).

A past Cleveland, Ohio pilot study using 6 in. columns showed high potential for treating CSO's by a fine screening/HRF system (89). A large scale (30 in. diameter) fine screening/HRF pilot system (Figure 5) was evaluated in New York, New York for the dual treatment of dry- and wet-weather flows (90). Removals of SS and BOD were 70 and 40 percent, respectively. The screening portion of the NYC project used a 70 mesh Discrostrainer which produced a high solids content cake which can eliminate a sludge-concentrating step. Results from a 5.0 MGD screening and DAF demonstration pilot plant in Milwaukee, Wisconsin indicate that

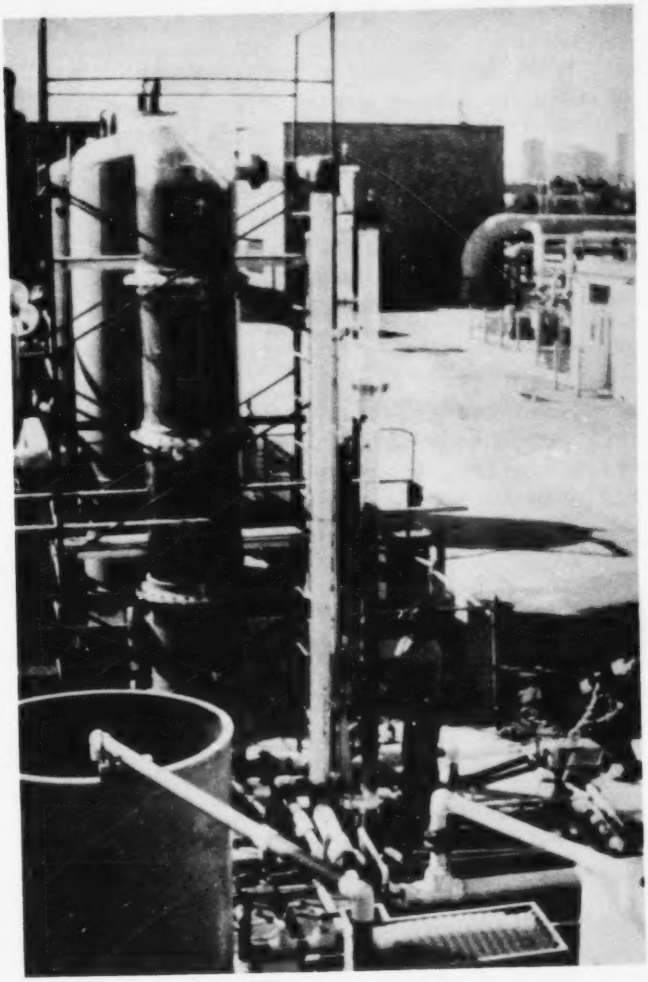


Figure 5. A Large Scale (30 in. Diameter) Fine Screening/HRF Pilot System.

greater than 70 percent removals of BOD and SS are possible (91,92). By adding chemical coagulants, 85 to 97 percent phosphate reduction can be achieved as an additional benefit.

Based on Program pilot plant studies, two full-scale screening/DAF prototype systems (20 and 40 mgd) have been demonstrated (93). Removals of SS and BOD were 70 to 55 percent, respectively. Treatment processes, e.g., microscreens and DAF are now being used by municipalities.

The swirl has also been developed for grit removal. The small size, high efficiency and absence of moving parts offer economical and operational advantages over conventional degritting facilities.

A full-scale demonstration of a (16 ft diameter/11 MGD design flow rate) swirl degritter has been completed in Tamworth, Australia (94,95). Removal efficiencies confirmed laboratory results. Compared with a conventional grit chamber construction costs are halved, and operation and maintenance costs are considerably lower.

Biological Treatment

The biological processes contact stabilization (96-98) have been demonstrated. They have had positive evaluation, but with the exception of long term storage lagoons, they must operate conjunctively with dry-weather flow plants to supply biomass, and require some form of flow equalization.

Disinfection

Because disinfectant and contact demands are great for storm flows (99), research has centered on high-rate applications by static and mechanical mixing, higher disinfectant concentrations (100-104), and more rapid oxidants, i.e., chlorine dioxide (101-104), ozone (100), and ultraviolet (UV) light; and on-site generation (100,105,106). Demonstrations in Rochester, New York (101); Syracuse, New York (104); East Chicago, Indiana (107); and Philadelphia, Pennsylvania (103), indicate that adequate reductions of fecal coliform can be obtained with contract times of two minutes or less by induced mixing and dosing with chlorine and/or chlorine dioxide. A pilot scale UV demonstration with a contact time of less than ten seconds is underway at New York City, New York.

The hypochlorite batching facility is still being used in New Orleans to protect swimming beaches in Lake Poncetrain (106). The SCSP Program supported the development of a brine hypochlorite generator now being used in industry (105).

Treatment/Control Design Guidebook

A compilation of the SCSP's best research efforts in CSO treatment/control over the past 18 years has been published (86).

Table 4. Wet-Weather Treatment Plant Performance Data

Device	Control Alternatives	Design Loading Rate (gpm/ft^2)	Removal Efficiency (%)	
			BOD$_5$	SS
Primary	Swirl Concentrator	60	25-60	50
	Microstrainer	20	40-60	70
	High-Rate Filtration	24	60-80	90
	Dissolved Air Flotation	2.5	50-60	80
	Sedimentation	0.5	25-40	55
	Representative Performance		40	60
Secondary	Contact Stabilization		75-88	90
	Physical-Chemical		85-95	95
	Representative Performance		85	95

Treatment Process Performance

Treatment performance in terms of design influx rate (GPM/ sq ft) and BOD5 and SS removal efficiency is provided in Table 4. The high-rate performance of the swirl, and the microstrainer, screening HRF on screening/DAF systems, is apparent when compared to sedimentation.

Sludge/Solids

Another program area is the sludge and solids associated with storm flow treatment. Sludge handling and disposal must be considered an integral part of CSO treatment because it significantly affects the efficiency and cost of the total waste treatment systems. Studies have shown that the annual quantity of CSO solids is at least equal to solids from dry-weather flow (108). This is a significant finding for the Construction Grants Program. The results of a project on CSO sludges are covered in three published reports covering: characterization (108), impact assessment (109), and treatability (110).

INTEGRATED SYSTEMS

The most promising and common approach to urban storm flow management involves the integration of control and treatment. Integrated systems is divided into storage/treatment, dual-use wet-weather flow/dry-weather flow facilities, and control treatment/reuse.

Storage/Treatment

When there is storage, there is treatment by settling, pump-back/bleed-back to municipal works, and sometimes disinfection treatment which receives detention also provides storage. The break-even economics of supplying storage must be evaluated when treatment is considered. The Program has demonstrated all of these storage/treatment concepts full scale.

Dual-Use Wet-Weather Flow/Dry-Weather Flow Facilities

The concept of dual use is -- maximum utilization of wet-weather facilities during non-storm periods and maximum utilization of dry-weather facilities during storm flows. The Program has demonstrated the full-scale dual-use of high-rate trickling filters (111), contact stabilization (96-98), HRF (90), and equalization basins (112). Various municipalities are employing dual-use microscreening.

In Clatskanie, Oregon, we evaluated a full-scale facility constructed to alleviate flow bypassing caused by excessive infiltration. The plant is in permanent use. Both wet- and dry-weather flow treatment is provided for in the same units and consists of primary sedimentation and conventional activated sludge for dry-weather periods converting to DAF and contact stabilization for wet-weather periods (96,97).

Control/Treatment/Reuse

"Control/Treatment/Reuse" is a catch-all for all integrated systems. A prime consideration should be the various nonstructural and land management techniques. In Mt. Clemens, Michigan, a series of three "lakelets" have been incorporated into a CSO treatment/park development (113). Treatment is being provided so that these lakes are aesthetically pleasing and allow for recreation and reuse for irrigation.

RECOMMENDATIONS FOR THE FUTURE

Receiving Water Impacts

Ties between receiving water quality and storm flow discharges must be clearly established and delineated. Quantification of the impairment of beneficial uses and water quality by such discharges is a major goal. Project results indicate the potential for significant impact to receiving waters of wet-weather flows. Control of runoff pollution can be a viable alternative for maintaining receiving water quality standards. However, the problems found seem to be site-specific in nature. Therefore, site-specific surveys are required that must consider the effects of larger materials and floatables near the outfalls. Based on results from these surveys, control may be warranted.

Toxics Characterization and Control/Treatment

Results from a limited in-house effort and the Nationwide Urban Runoff Program indicate that urban stormwater runoff and CSO contains significant quantities of priority pollutants. Additional investigation of the significance of concentrations and quantities of toxic pollutants with regard to their health effects or potential health effects and ecosystem effects is required. A need exists to evaluate the removal capacity of alternative treatment technologies for these toxics and to compare their effectiveness with estimated removal needs to meet water quality goals.

Sewer System Cross Connections

Investigations have shown that sanitary and industrial contamination of separate storm sewers is an extensive nationwide problem. In other words, a significant number of separate storm water drainage systems function as combined sewer systems. Therefore, a nationwide effort on both federal and local levels, to alleviate the pollution impacts from discharges of these systems, is required. It is better to classify such bastardized drainage systems as combined systems for pollution control priorities.

Integrated Storm Water Management

The most effective solution methodology for wet-weather pollution problems must consider: (1) wet-weather pollution impacts in lieu of blindly upgarding existing municipal plants, (2) structural vs. non-structural techniques, (3) integrating dry- and wet-weather flow systems to make maximum use of the existing drainage during wet conditions and maximum use of wet-weather control/treatment facilities during dry weather, and (4) the segment or bend on the percent pollutant control vs. cost curve in which cost differences accelerate at much higher rates than pollutant control increases, although load discharge or receiving water requirements will dictate, ultimately, the degree of control/treatment required.

Flood and erosion control technology must be integrated with pollution control, so that the retention and drainage facilities required for flood and erosion control can be simultaneously designed or retrofitted for pollution control. If land management and non-structural techniques are maximized and integrated, there will be less to pay for the extraction of pollutants from storm flows in the potentially more costly downstream plants.

Institutional Socio/Economic Conflicts

Some of the most promising opportunities for cost-effective environmental control are multipurpose in nature. However, there are institutional problems that hinder their implementation. First, the autonomous Federal and local agencies and professions involved in flood and erosion control, pollution control, and land management and environmental planning must be integrated at both the planning and operation levels. Multi-agency grant coverage must be adequate to stimulate such an approach. For example, the EPA would have to join with the Corps of Engineers, Soil Conservation Service, Department of Transportion, and perhaps other Federal agencies as well as departments of pollution control, sanitation, planning, and flood control at the local level.

Another problem is that construction grant (and other) incentives are geared towards structurally intensive projects which may counter research findings in the area of optimal solutions. Optimized wet-weather pollution involves a city-wide approach including the integration of structural as well as low-structural controls. The low-structural measures are more labor intensive. Construction grant funding does not presently address this expense and, accordingly, municipalities are discouraged from using them.

CONCLUSIONS

In general, on a mass basis, toxics, bacteria, oxygen demanding, suspended, and visual matter in CSO and urban storm water are significant. Ignoring the problem, because it seems to be too costly to solve, will not make the problem go away. The integrated approach to wet-weather pollution control is the only way which is going to be feasible, economical and, therefore, acceptable. Potentially tremendous "bangs for the bucks" can be derived from wet-weather pollution control research fostering integrated solutions. As you can see, the Program has investigated a problem, proven its significance, and developed a gamit of design and control techniques. Better advantage needs to be taken of proven technology.

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PANEL DISCUSSION: STATUS AND FUTURE OF CSO REGULATIONS IN ILLINOIS
FRIDAY, OCTOBER 21, 1983

Moderator: John R. Pfeffer, Professor, Environmental Engineering, University of Illinois at Urbana-Champaign.

Participants:

Michael MacMullen, Chief Monitoring and Standards Unit USEPA Region V, Chicago.

Joan Anderson, Member, Illinois Pollution Control Board, Chicago.

Toby Frevert, Technical Standards Unit, Division of Water Pollution Control, IEPA, Springfield.

James Pappas, Executive Director, Bloomington Normal Sanitary District Bloomington.

John Pfeffer - Let us start the panel discussion with a statement from each participant on how their organization is involved with Combined Sewer Overflow regulation.

Joan Anderson - The PCB has 5 soon to be 7 technical members who are appointed by the Governor. The PCB is part of the Environmental Protection Act. The Act originally designated the IEPA as the enforcement Agency and the Department of Energy and Natural Resources as the research Agency. The PCB has 2 main functions it promulgates the environmental regulations for the State and it handles adjudicatory functions such as variances, permit appeals and enforcement actions. The PCB conducts its regulatory proceedings in a somewhat quasi-judicial mode with sworn testimony, orders, opinions and direct appeal to the Appellate Court. PCB regulations can be overturned if the courts rule that the PCB has acted in an arbitrary or capricious manner.

The rulemaking process in Illinois is a long one, governed by the Environmental Protection Act and the Administrative Procedures Act. The Environmental Protection Act mandates that the Board provide public notice of a regulatory proposal at least 20 days prior to conducting public hearings on the proposal. All proposals of substantive state wide regulations require at least two public hearings to consider the merit and substantive issues of the proposed rule. Under Chapter 96 1/2 the Department of Natural Resources (DENR) must prepare an Economic Impact Study on the rule. Upon completion of the DENR study at least two additional public hearings are required to address the economic aspects of the proposed study.

After completion of the rulemaking procedures under the Environmental Protection Act the PCB must promulgate the rule through the requirements of the Illinois Administrative Procedure Act. The Board proposes an order and an opinion and publishes the order for first notice in the Illinois Register. Then there is a 45-day comment period on the rule, and a public hearing if warranted by citizen interest. A second notice is sent to the Legislative Joint Committee on Administrative Rules at which point neither the public or the Board can charge the rule unless it is in response to an objection by the Legislative Committee. Finally the rule is sent to the State Library and the Secretary of State for "form" review and filing. If the process is not completed in a year you must reissue the first notice and reinitiate the process.

The CSO issue has generated a lot of interest because of the frustration municipalities have expressed by the requirement in rule 602 for full treatment of the first flush and ten times the dry weather flow capture. The PCB conducted inquiry hearings around the State and concluded that this rule may not be economically or environmentally justified for many facilities. As a result of comments from IEPA and many others on the problem, an exception procedure to rule 602 was developed. A mechanism was set up to satisfy the needs of the public for hearings, the needs of the discharger to get upfront help from the Agency, the need of the Board to have a reasonably legal rule and the need for everyone to save time in terms of the rulemaking procedure. The exception procedure enables good individual packages yet retains the statewide rule which in essence has become a maximum not a minimum. Toby will detail the program.

This is definitely a pilot project in rulemaking where if the Agency and discharger can lock arms and come in with an implementation plan package at the hearing which is agreeable to the public, the board will generally allow that plan to be implemented under the exception procedure.

Therefore the Board can get the exception through in 45 days instead of the usual length of one to two years. We hope that this exception procedure will make a terribly frustrating rulemaking process more flexible and if the exception process is successful there are areas in air, land and hazardous waste where the process can be applied because of the similar needs for flexibility but also a statewide standard.

Toby Frevert - The critical element in getting the Agency's CSO program started is to identify the criteria which municipalities can use to explore their systems and receiving streams at and below overflow points, to determine if any CSO related problems exist and if they do, how extensive a problem exists. The criteria which will be used in the assessment were finalized and sent through the rulemaking process last spring shortly after the Board's Exception Regulation was adopted.

There are approximately 100 communities in Illinois which have CSO problems and have expressed interest in working jointly with the Agency to develop a cheaper solution to their CSO problems than was possible under the first flush rule which was on the books. If these communities had proceeded to correct the CSO problems via the original rule they would have had to conduct intensive studies. Since many of the CSO's affect more than one stream in the community, the cost of the studies themselves could be exorbitant. The new program is a phased approach in which each step of the evaluation determines whether the next step is necessary. The sequence of phases is as follows.

1. Collection of background information including that available from construction grants facility planning activities. This information had to be submitted to the Agency by October 1, 1983 and 50-60 communities have submitted reports.

2. Onsite inspection of overflow spots, by the municipalities. Five or six municipalities have progressed to the step.

3. Decision on whether a sophisticated study on biological, chemical and physical properties of the stream, is necessary based on the knowledge of land use and obvious environmental problems.

4. Drawing up the mutually agreeable plan between the discharge and IEPA to correct the CSO.

I forsee many municipalities getting involved in the process fairly rapidly specifically because of the October 1984 deadline for CSO eligibility in terms of general eligibility and because of the reduction in the percentage of the State's grant allotment that can be used for CSO's based on the Governor's discretion. Even after the reduction of funds the IEPA anticipates there will be some grant funds expended on CSO control in the State. In summary the purpose of the program is to ensure that specific needs related to CSO are determined and that no more grant money or local funds are spent on correcting the problem than is absolutely necessary.

James Pappas - The Bloomington-Normal Sanitary District developed a water quality monitoring network three years ago. There are 13 stations located upstream and downstream of CSO's. In addition we sampled as far as 4 miles downstream of the treatment plant. Monitoring results indicate that the water quality in Sugar Creek is of good quality. The monitoring system was expanded to determine how frequently the overflows were triggering and to determine whether they were overflowing due to structural failure, too much water in the system or blockage. The District began to monitor 10 of the overflow points in the City five days a week. The District found that some of the overflows are strictly operational problems which were controllable. Through the monitoring we also got an idea of which CSO's occur more frequently which enables further analysis.

All four phases of the IEPA technical policy have been completed and the report was submitted to IEPA on September 30, 1983. The report included a biological survey completed at 19 biological monitoring points extending 14 miles below the facility. The biological information correlated well with the water quality information. The CSO's as far as we can determine have a minimum effect. Some of the water quality impacts appear more closely attributable to temperature and low flow in the stream.

In order to solve CSO problems by complete elimination as required by rule 602 prior to the exception procedure would have cost 25-28 million dollars. Our study indicates that CSO is not a major problem so why spend 25-28 million dollars to solve a minor problem. We feel we can considerably reduce the frequency of overflows by spending 1.9 million dollars. Of that 1.9 million, 1.3 million is associated with installing a relief interceptor. Although the District has wet weather treatment capacity we do not have the transport capacity in wet weather conditions. Another portion of the money will be utilized to install a grit chamber. During our study we found that the 51" interceptor which takes a large portion of the CSO flow contained significant amounts of grit. The interceptor was cleaned and a monthly monitoring program initiated. The deposition of grit was measured on 25 points along the interceptor to determine where the grit was coming from, where it is depositing, and at what frequency it was depositing. The proposed solution is to install a grit removal facility on the major trunk sewer coming into the interceptor. We will keep the interceptor at full transport capacity and by doing this we reduce the CSO frequency at that location at a cost of $200,000. We will also do some repiping work. We feel we have a technologically and economically feasible program which is affordable locally. This is something which is less than a full scale solution for the CSO but you don't need a full scale solution because we don't have a significant problem.

We have not spent a lot of time on the quality of the CSO itself because the quality of the stream does not indicate a need. The work that has been done indicates that the quality of the CSO is not too different from stormwater. Our CSO's are designed to trigger an overflow when there is significant dilution capacity in the stream. We didn't find any sludge deposits in the stream downstream of the CSO's. It seems that the stream naturally able to assimilate the pollutant loads from the CSO and the monitoring programs shows this is to be true.

Mike MacMullen - There are over 500 facilities in Region V that have combined sewers which occassionally overflow. According to the needs survey conducted in 1982 it would cost almost 12 billion dollars to alleviate and abate these CSOs. Thus far 1/2 billion dollars have been spent in Region V to fund CSO projects. The criteria used to determine project funding are two-pronged. The numbers contained in the standards are examined and USEPA asks how much money is necessary to reach standards. USEPA also does a marginal benefit analysis that attempts to plot units of pollutants removed vs the incremental cost of removal.

As of October 1, 1984 the limited funds we have for assisting communities to build CSO structures will be less and access to these funds will be more difficult. Given this situation it becomes particularly important for decision makers to know what the operational capability of the individual systems are. This could be established by requiring a development of CSO control plan in the NPDES permit issued to the discharger. A control plan should be required by a specific date, 1-3 years after the permit is issued. Once a plan is completed the NPDES permit could then require that the system be operated in accordance with the control plan.

When USEPA reviews dry weather treatment projects that propose more than secondary treatment an attainability analysis is required by USEPA. We ask whether attainability of the standard can be documented and justified in terms of the potential uses that have been either denied or impaired, and will their denial be removed by the proposed strategy. It is not unreasonable to suppose that when USEPA is asked to review CSO projects in the future a similar test might very well be put in place. If USEPA could not come to the same conclusion that the State and local government did for a proposed project this was because the analysis did not sufficiently indicate use attainability clearly enough in our judgement to come to a positive funding conclusion. This is specifically a funding decision and does not in any way relate to the enforceability of the state standard under state law. I believe that application of the quality standards will be changing to reflect increased attention for the attainability of designated stream uses as opposed to an almost exclusive focus on compliance with the quality criteria.

Karl Palmer - How long do you expect the median exceptions process to take if you go through the PCB.

Toby Frevert - This is variable. For the communities who have already begun the process and have started collecting their own data will probably see some resolution, in terms of the Agency and discharger coming to an agreement on what seems to be a desirable solution, by the end of the year or early next year. There is an expiration data on this process, and those cities who have not begun must have a joint or single petition for an exception on file with the PCB by January 1986.

Detailed biological sediment and water quality work takes 3-6 months to complete so it is impossible to generalize how long it will take districts to complete this.

From the broad range we are going to see dischargers and the agencies concurring on specific projects within the next several months and will hopefully wind up the entire process within 2 years. This of course somewhat depends on the funding of the grants program and availability of grant money which is unknown at this point.

Stephen N. VanWinkle - Mr. Pappas your analysis seems to indicate that CSO does not impact water quality that much, certainly not enough to justify the 25 million dollars you expected to spend to solve the entire problem. Why do you want to sepnd 1.9 million dollars if there is no problem?

Jim Pappas - I think we have certain obligations as a governing Agency to do what is technologically and economically feasible to upgrade our transport system. By putting in a relief interceptor, installing a grit system, and repiping we will have the capacity to run our interceptor system at full capacity when the need arises.

This may be a more philosophical approach. We could have sat back, done nothing let the Agency take enforcement action against us or try a legislative reprive but we have an obligation as a government agency to see that we are doing what we should be and one of these things is to have a good transport system. I had no trouble going to my Board of Trustees and saying this is what we need to spend on this type of construction in the future even if there were not a CSO regulation on the books. Also some of our problems are operational and these must be resolved by us not the IEPA or the PCB with or without grant funds. We will fight the Agency if we are forced to do more than what we feel is necessary.

Stephen VanWinkle - That was my point. You stated that regardless of whether you had a CSO problem that you would be involved in this work. What you are really doing is taking care of your system the way you think you should operate.

James Pappas - That is right. I don't need to have the IEPA tell me how to run my system. In order to have that freedom I need to make sure I'm doing what I should be doing.

Audience Question - What method did you use to determine the frequency of CSO's at the various sites.

James Pappas - We made observations at the overflow points. If the site was overflowing it received one code number for our computer. If it wasn't overflowing it received another code. We didn't monitor the duration of overflows because if you have a high groundwater table situation or a snowmelt situation you may have overflows every day without ever having any precipitation. We did record precipitation events and the type of precipitation. Thus we can expect certain overflows to trigger at certain conditions and so forth. We are developing a historical data base on these overflows and if they are overflowing for some reason they shouldn't be, we want to know the reason. We physically inspected every overflow and determined why overflows were occurring. Each cause was coded and the information placed in our computer. Thus we can quickly determine which overflows occur most frequently and why they overflow. Once we determine on which days there is overflow we go back to the water quality data and examine it to see how the CSO's are affecting the quality.

Toby Frevert - Jim, can you elaborate on which elements in the program you did with your own people and which element you relied on outside contractors to complete?

James Pappas - The District completed 80% of the CSO Technical Policy Program in house. We completed the physical inspection of the system, the grit monitoring and the flow measuring work. Our field people did all of the water quality monitoring. The district field personnel who are biologists collected samples under the supervision of a University professor. A graduate student identified the microinverbrate and macroinvertabrate data. We hired a consultant to pull the techical and scientific information together, draw up the conslusions, and make recommendations.

John Pffefer - MSD has been collecting data and conducting research to back their position for a long time. Downstate it is very rare to find a district that has made that effort. I think we are getting into a new era. If you don't begin to staff up to monitor your own streams and collect this data base you will always be behind and you are never going to be in a position to take advantage of the situation such as the one resulting from the exception process. I know that the local districts have not yet seen the light but they may someday.

Steve Kim - Do you think that most municipalities have the capability to carry out the type of monitoring program necessary for the exception process?

Toby Frevert - This program was developed on a phased basis. I personally see no major difficulties for the municipalities getting through phase 1 and 2 with their own resources, manpower, and judgements. When you get to the point where you have to get into the more detailed biological or complete chemical analysis, usually on the water column chemistry and sediment chemistry, you are probably going to fall back on consulting resources from the outside but I anticipate that in up to 50% of the cases there will not be the need to do that. An economical and appropriate solution may very well come to the surface and be obvious to you after you have gone out and done some basic observation on the system, identified what kind of land use you have, and what kind of growth patterns if any you are going to have. I think in many cases the answer is going to be obvious. If you have an overflow in a public park which is very accessible to people using that park you are probably going to want to eliminate that CSO, relocate it elsewhere or get a control installed which prevent that overflow or ensures that it overflows only on rare occasions. That decision isn't based on the aquatic community or fishable goals; but rather on a public health and aesthetic. In a public exposure area you don't need a biological survey to come to the conclusion that overflow has to be eliminated.

John Pfeffer - Toby you bring up an important point. By examining your system you can discover many problems without a lot of expenses and sampling. In Galesburg they had a similar situation and they discovered that their problems could be changed with some relatively minor insystem changes without major expenses.

James Pappas - When the Agency came out with what was necessary for phases 1, 2, 3, and 4 we had already completed through phase 2 1/2 but we sat down with the EPA, discussed what we had completed and what type of information the Agency was requesting. We then negotiated with them and by showing the Agency what we had completed we were able to eliminate some additional monitoring. Thus the phased approach appears to be working. When the Agency can get together with a discharger and develop a joint petition to file with the Pollution Control Board, that is progress in this State.

Greg Sherwood - I can see alot of situations where the communities are going to find a minimal water quality impact from CSO. I can also see a potential situation where philosophical arguments will have more impacts on cost rather than a cost-benefit analysis in terms of water quality benefits. I wonder if Mr. Frevert and Ms. Anderson could give us some insight into the kinds of philosophical agreements that are going to enter in situations where you do have minimal water quality impact, such as in Bloomington-Normal.

Decisions made by a local government that affect areas different from the areas directly served by, or taxed by, that government will be handled differently by different communities. For example, some communities are less reluctant than others to spend money to repair their sewers so as to solve a CSO problem that will provide relief primarily to a downstate community. In addition the philosophical arguments about what is our corporate duty tends to focus within the boundary of the entity involved. I do not expect to see any simple philosophical approach. Communities do differ, their histories differ, and, like industries, there are some who are better corporate citizens than others.

Toby Frevert - I can see alot of cases in which you can not specifically document severe water quality problems due to CSO. I feel it is still wise to go in and look at that system and determine what can be done to make the system more dependable and operating more like it was designed to operate. Some of these systems are 50-100 years old. They have some flaws which create maintenance problems in addition to CSO problems. In these cases the philosophical element is going to be considered but will not be enough to warrant a 20-40 million dollar project.

James Pappas - To give you an example of how important I find this agrument, lets say the philosophy is to capture first flush in terms of BOD and suspended solids. You may have a situation during first flush where if you look at only BOD alone you would spend zero dollars and if you look at suspended solids you might spend 40 million dollars. All your philosophical agrument does is bracket your expendatures from 0 - 40 million dollars and that kind of discussion should not be based on philosophical arguments alone. They should have some type of sound scientific basis behind them.

Joan Anderson - It would be a lot easier if we could get a perfectly sound scientific or engineering basis for everything we do but if we waited for that type of soundness we would not be doing anything.

Stephen VanWinkle - Going back to Mike MacMullen's comments this morning and afternoon concerning funding, after October 1, 1984 at least 80% of the USEPA funding available will not be related to CSO type problems. Jim Pappas stated that he feels obligated to spend 1.9 million on his system not really based on CSO but based on system analysis and of what could be done to make the system operate better on a transport basis. Would the 80% be eligible for that kind of concern?

Michael MacMullen - It could be but the funding situation is more complicated than your question. Currently CSO is an eligible type of project just like any other type of project. Starting October 1, 1984 the Governor has the capability to fund projects that are not otherwise eligible out of the 20% set aside. If the projects like CSO go beyond that 20% set aside there are still some opportunities to submit that to

USEPA consideration. If you do this the project is going to have to run through a Regional Office and Headquarters review. As I suggested you should not be surprised if we get into an attainability type procedure in determining whether to fund a project that is submitted for special review.

The funding decisions are getting more complicated than before. As a society we have already addressed alot of the easier and more straightforward pollution abatement problems. They have not all been addressed but we are making progress. What is left is a series of incredibily complex problems that are subject to multiple interpretations and are subject to vastly different judgements depending on who applies the judgement. There is a need like there has never been in the past for municipal and state pollution control representatives and Federal USEPA representatives to sit down and do some hard and firm talking. This includes discussions on what the choices are and what the constraints are that are imposed upon the local communities, and why they are thinking the way they are and why they are making the proposals they are. I think that in the past the USEPA has tended to view our overview and review role as an after the fact process. If we had perhaps been more outgoing in the beginning and made an effort to sit down with communities and the State Pollution Control Agency while they were developing their decisions and recommendations we could have saved outselves a lot of trouble. With the tightened time frame and the reduced dollars we simply must expand our capabilities to communicate more effectively upfront in the future.

Audience Question - Even after you get outside the metropolitan area, for instance the Fox River Valley, you may have a series of communities with CSO's entering the river very close together. Is the Board going to approach each CSO one at a time or make some attempt to integrate all 3 or 4 or more communities involved.

Joan Anderson - You must realize that CSO's are a common problem for many communities in many stream segments and that you cannot administratively or programatically approach these in a vacuum. Hopefully this exception procedure will avoid this better than the usual site specific exception.

Nathan Wilcoxin - I know some specific cases where there are no CSO impacts at all and yet municipalities must go through site specific variances. Are there some short cuts so you don't have to wait as long a time for an exemption decision.

Joan Anderson - The entire purpose of this exception procedure is to speed up the variance procedure and to end up providing enough information to the Pollution Control Board so that it can make a sensible decision on where to go. The procedure is set up to allow disagreement between the Agency and applicant. Without this exception procedure the Agency could not voice disapproval early in the process. The Agency might know what the problem is and you might propose a solution that IEPA doesn't like. In our regular rulemaking procedure the Agency cannot upfront say that this is the wrong solution, they have to make you present your information and they could prejudice themselves. Under this procedure the Agency can say if you believe it and you can make us believe it then the proposal will go through and go through rather quickly.

Toby Frevert - I would like to add to that comment if I may. From the Agency's point of view, if indeed there is no impact from an overflow and that can be readily demonstrated, that discharger will not go through the full program. Our guidance criteria is intended to operate as a screening process to identify where detailed water quality assessments are necessary and where they can be dispensed with. Under the circumstances described in the question, the environmental assessment would be abbreviated, the full extent of evaluations outlined in our criteria would not be necessary and the discharger would be in a position to file his exception petition in a much shorter time with much less effort then someone with a less obvious absence of environmental impact.

John Pfeffer - Mrs. Anderson you were talking about this exception being applied to some other areas. I wonder if this exception will be applied to some other water quality areas?

Joan Anderson - It appears that legislative change may be necessary before this program is expanded to additional areas. We are now examining this possibility. However at this time it would be appropriate to examine how successful this program is before attempting expansion.

URBAN EFFECTS ON WATER QUALITY AND QUANTITY

October 20-21, 1983
Jumer's Castle Lodge
Urbana, Illinois

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